ESTCP
Cost and Performance Report

(MR-201314)

Empirical Evaluation of Advanced Electromagnetic Induction Systems - Factors Affecting Classification Effectiveness in Challenging Geologic Environments

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14. ABSTRACT
This report details the Environmental Security Technology Certification Program (ESTCP) Munitions Response Live Site Demonstrations at New Boston Air Force Station (NBAFS), performed in the summer of 2013, and at Munitions Response Site (MRS) R-04A West, at Tobyhanna Army Depot (TOAR) Formerly Used Defense Site (FUDS), in Pennsylvania, performed in the summer of 2015.

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ACRONYMS AND ABBREVIATIONS

ACD	analyst calibration dig
AGC	advanced geophysical classification
CH2M	CH2M HILL, Inc.
cm	centimeter
.csv	comma separated values
DMM	discarded military munitions
EMI	Electromagnetic Induction
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
Geosoft	Geosoft Oasis montaj
GPS	Global Positioning System
GRD	Geosoft grid
HE	high explosive
IMU	inertial measurement unit
ISO	Industry Standard Object
IVS	Instrument Verification Strip
JD	Julian Day
lb	pound(s)
m	meter
MEC	munitions and explosives of concern
mm	millimeter
MMRP	Military Munitions Response Program
MPPEH	Material Potentially Presenting an Explosive Hazard
MPV	man portable vector
MQO	measurement quality objective
MR	munitions response
MRS	munitions response site
MRSIMS	Munitions Response Site Information Management System
mV/A	millivolts per ampere
ms	milliseconds
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NBAFS	New Boston Air Force Station

NH	New Hampshire
NRL	Naval Research Laboratory
PLS	Professional Land Surveyor
QC	quality control
RMS	root mean square
ROC	receiver operating characteristic
RTK	real-time kinematic
RTS	robotic total station
SNR	signal-to-noise ratio
TEM	transient electromagnetic
.tem	Input template file
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOAR	Tobyhanna Army Depot
TOI	Target of Interest
Tx/Rx	transmit/receive
UTM	Universal Transverse Mercator
UXA	UX-Analyze
UXO	Unexploded Ordnance

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EXECUTIVE SUMMARY

In 2013 and 2015, CH2M HILL, Inc. (CH2M) performed two Environmental Security Technology Certification Program (ESTCP) Munitions Response Live Site Demonstrations as part of project MR-201314. The 2013 demonstration was performed at the Shooting Fields (MU705), located at New Boston Air Force Station (NBAFS), New Hampshire (NH). The 2015 demonstration was performed under the existing project at Munitions Response Site (MRS) R-04A West, at Tobyhanna Army Depot (TOAR) Formerly Used Defense Site (FUDS), in Pennsylvania.

CH2M performed the demonstrations at NBAFS and TOAR using the Naval Research Laboratory (NRL) Time-domain Electromagnetic Towed Array Detection System 2x2 (TEMTADS), an advanced transient electromagnetic (TEM) system designed for the detection and classification of munitions and explosives of concern (MEC) (specifically discarded military munitions [DMM] and unexploded ordnance[UXO]). Additional data was collected at each of these sites by Black Tusk Geophysics using the Man Portable Vector (MPV) but those results are not addressed in this report.

The demonstration at NBAFS was designed to investigate the classification methodology at a site suspected to contain a high density of subsurface metallic objects, as well as a variety of munitions such as 20-millimeter (mm) projectiles. The TEMTADS was employed in both dynamic and cued modes using the sensor's standard wheel configuration. Positioning was achieved through the use of a real time kinematic (RTK) global positioning system (GPS).

Approximately 6.1 acres were mapped with the TEMTADS system in dynamic mode. The density of geophysical anomalies identified from the survey was an order of magnitude higher than anticipated. In order to stay within the budgeted scope of the demonstration, 1,500 anomalies from a subarea of the site were selected for cued interrogation with the same system. Data analysis of the cued measurements confirmed a high density of metal with a large percentage of the anomaly locations being multi-target scenarios. The project team (ESTCP, NBAFS, and CH2M) was haulted after a several week review of intrusive results, which determinined that classification at the site would 1) not result in cost savings as opposed to intrusively investigating all anomalies and 2) be ineffective. This decision was based on the fact that 70 percent of the intrusive investigations resulted in discovery of a target of interest (TOI) and each dig typically yielded multiple items. Approximately 33 percent of the anomalies investigated resulted in three or more sources and, under these circumstances, the inversion results do not appear to accurately represent the ground truth.

The demonstration at TOAR was designed to investigate the use of advanced electromagnetic induction (EMI) sensors at a densely wooded site with challenging micro-terrain features (e.g., impact craters, rocks, boulders, and gullies) for detecting munitions down to the size of 37-mm projectiles. The TEMTADS was employed in both dynamic and cued modes in two-person litter mode and positioning was achieved through the use of a Robotic Total Station (RTS).

Approximately 0.71 acre was mapped with the TEMTADS system. Production was significantly hindered by the remote location and site conditions and coverage for only one of the four grids initially selected for investigation was at 100 percent (not including gaps because of physical obstructions).

Dynamic surveying is very much a function of terrain, navigation software, and deployment platform. Because of the challenging conditions at TOAR, production rates achieved as part of the demonstration are estimated to be much lower than production rates at sites with more favorable conditions.

A total of 429 anomalies were identified by the TEMTADS dynamic data analysis. These anomaly locations, and an additional 68 targets selected from the MPV dynamic data, were interrogated (cued data collection) with the TEMTADS system. The cued data were used to classify each target as being a TOI (dig) or high-likelihood non-TOI (do not dig). The TEMTADS data collection and analysis resulted in successful detection and classification of all known TOIs (seeds and native).

The estimated cost of deploying the TEMTADS based on the demonstrations at NBAFS and TOAR is high, approximately two or three times the cost of deploying commercially available systems such as the Geonics EM61-MK2. The primary demonstrated advantage of deploying the TEMTADS lies with the ability to use the data collected to classify targets and thus to produce a prioritized dig list. At TOAR, the use of a prioritized dig list would have reduced the number of digs by 71 percent or more (depending on the stop dig threshold). This would result in an overall cost savings of approximately 30 percent in the cost of the intrusive investigation. For sites such as TOAR, where targets are successfully discriminated, the higher cost associated with deployment of the TEMTADS is justified on the basis that it can substantially reduce the cost of digging. For sites such as NBAFS, where the anomaly density is very high and detecting munitions down to the size of 20-mm projectiles is required, use of the TEMTADS is not warranted.

1.0 INTRODUCTION

This demonstration cost and performance report details the Environmental Security Technology Certification Program (ESTCP) Munitions Response Live Site Demonstrations at New Boston Air Force Station (NBAFS), performed in the summer of 2013, and at Munitions Response Site (MRS) R-04A West, at Tobyhanna Army Depot (TOAR) Formerly Used Defense Site (FUDS), in Pennsylvania, performed in the summer of 2015.

At both sites the Naval Research Laboratory's (NRL) man-portable version of the Time-domain Electromagnetic Towed Array Detection System 2x2 (TEMTADS) was employed in both dynamic and cued modes. Positioning was achieved through use of a real-time kinematic (RTK) global positioning system (GPS) at NBAFS and a Robotic Total Station (RTS) at TOAR. (Additional data were collected at each of these sites by Black Tusk Geophysics using the Man Portable Vector [MPV] but those results are not addressed in this report.) The demonstrations were performed in accordance with the *ESTCP Munitions Response Live Site Demonstrations, New Boston Air Force Station, NH, Demonstration Plan* (ESTCP, 2013) and the *Live Site Demonstrations TEMTADS 2×2 Demonstration Plan MRS-R04A (West), Tobyhanna Army Depot FUDS, Pennsylvania, ESTCP Project MR-201314* (ESTCP, 2015), respectively.

1.1 BACKGROUND

A large quantity of FUDS and Base Realignment and Closure land has been contaminated with munitions and explosives of concern (MEC), and specifically discarded military munitions (DMM) and/or unexploded ordnance (UXO). Changes in the land use designation for these areas often requires a munitions response remedial action to remove hazardous items before reuse. Using conventional technology and procedures, remediation costs are driven by the need to visually characterize all metal targets; however, most targets are non-hazardous scrap with only a small percentage actually being classified as dangerous. Significant overall cost savings can be achieved using technology that reliably classifies metal targets and substantially reduces the number of required intrusive investigations. The demonstrations at NBAFS and TOAR were intended to help constrain the environments in which advanced geophysical classification (AGC) technology could be effectively applied at sites with challenging conditions and still result in a significant reduction in intrusive activities.

CH2M HILL, Inc. (CH2M) served as contractor to ESTCP under contract W912HQ-13-C-0039 for the demonstrations at NBAFS and TOAR. The demonstration at NBAFS was designed to investigate the use of the TEMTADS sensor at a site that contained a high density of metal in the sub-surface and a large variety of TOI down to 20-millimeter (mm) projectiles. The demonstration at TOAR was designed to investigate the use of the TEMTADS sensor at a densely wooded site with challenging micro-terrain features (e.g., impact craters, rocks, boulders, gullies) for detection of 37-mm projectiles. As a result of the site conditions at TOAR, the TEMTADS was operated in two-person litter carry mode during dynamic (i.e., detection) data collection.

1.2 OBJECTIVES OF THE DEMONSTRATION

The overall objective of both demonstrations was to demonstrate the overall detection and classification performance of the TEMTADS; however, the site specific objectives of the two demonstrations where slightly different.

1.2.1 NBAFS

At NBAFS, the overall objective was to demonstrate the detection and classification performance of the sensor at a site with a heavy density of metal and targets of interest (TOI) as small as 20-mm projectiles. CH2M performed the following tasks in order to achieve this overall objective.

- Placement of subsurface quality control ('blind') seeds within the demonstration site
- Establishment of an instrument verification strip (IVS)
- Collection of dynamic data using the TEMTADS
- Processing of dynamic data and selection of targets
- Cued interrogation of targets using the TEMTADS
- Processing of cued geophysical data
- Reacquisition and intrusive investigation of targets

1.2.2 TOAR

At TOAR, the overall objective was to demonstrate the detection and classification performance of the sensor in challenging terrain conditions and for TOI as small as 37-mm projectiles. A secondary objective was to provide data to ESTCP for comparison of the TEMTADS capabilities under these conditions to those of the MPV. (Note that this report covers the TEMTADS operations and analysis only; comparison of the results achieved with those of the MPV was performed by the ESTCP Program Office). To achieve these overall objectives CH2M performed the following tasks.

- Collection of dynamic transect data across using a Geometrics G-858G magnetometer to identify an appropriate demonstration area
- Selection of the demonstration grids based on G-858G data
- Reduction of vegetation
- Placement of subsurface quality control ('blind') seeds within the demonstration site
- Establishment of an IVS
- Collection of dynamic data cueing the TEMTADS
- Interrogation of cued targets using the TEMTADS
- Processing of dynamic and cued geophysical data
- Reacquisition and intrusive investigation of targets selected for cued interrogation

1.3 REGULATORY DRIVERS

The Military Munitions Response Program (MMRP) is charged with characterizing and, where necessary, remediating MRSs. When a MRS is remediated, it is typically mapped with a geophysical system, based on either a magnetometer or EMI sensor, and the locations of all detectable signals are investigated. Many of these detections do not correspond to munitions, but rather to other harmless metallic objects or geology. Field experience indicates that often in excess of 90 percent of objects excavated during the course of a munitions response are found to be nonhazardous items. Current geophysical technology, as it is traditionally implemented, does not provide a physics-based, quantitative, validated means to discriminate between hazardous munitions and nonhazardous items.

With no information to suggest the origin of the signals, all anomaly sources are currently treated as though they are intact munitions when they are investigated. They are carefully excavated by certified UXO technicians using a process that often requires expensive safety measures, such as barriers or exclusion zones. As a result, most of the costs to remediate a munitions-impacted site are currently spent on excavating items that pose no threat. If these items could be determined with high confidence to be nonhazardous, some of these expensive measures could be eliminated or the items could be left unexcavated entirely.

The MMRP is severely constrained by available resources. Remediation of the entire inventory using current practices is cost prohibitive within current and anticipated funding levels. With current planning, estimated completion dates for munitions response on many sites are decades out. The United States Department of Defense's Defense Science Board observed in its 2003 report that significant cost savings could be realized if successful classification of munitions and other nonhazardous sources of anomalies could be implemented. If these savings were realized, the limited resources of the MMRP could be used to accelerate the remediation of MRSs that are currently forecasted to be untouched for decades.

While no regulatory barriers exist barring the application of advanced EMI technology (such as the TEMTADS) at sites contaminated with DMM/UXO, convincing regulators and other stakeholders of the reliability of advanced EMI systems classification of metal targets is often challenging. The demonstrations at NBAFS and TOAR were designed to help the ESTCP Program Office address these challenges by evaluating the capabilities of the TEMTADS at sites with challenging conditions.

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2.0 TECHNOLOGY

CH2M's demonstrations at NBAFS and TOAR were designed to investigate the use and document the capabilities of the TEMTADS advanced EMI sensor at sites with challenging conditions (e.g., dense woods, high anomaly density, small TOI, and varying micro-terrain features) through dynamic and cued data collection. Analysis of the data was performed using conventional and AGC-specific data processing methods.

2.1 TECHNOLOGY DESCRIPTION

2.1.1 TEMTADS 2x2

The TEMTADS is comprised of four individual sensor elements arranged in a 2-by-2 array. Each element consists of a transmit coil and a three-axis receiver cube. Each cube has dimensions of 8 centimeters (cm). The center-to-center distance is 40 cm, yielding an array measuring 80 cm by 80 cm. A TEMTADS sensor element under construction, the sensor array (with protective cover removed), and a schematic diagram of the array are shown as **Figure 2-1**. Decay data are collected with a 500-kilohertz sample rate until 25 milliseconds (ms) after turn off of the excitation pulse. This results in a raw decay of 12,500 points, which is too many to be used practically. These raw decay measurements are grouped into 122 logarithmically spaced 'gates' with center times ranging from 25 microseconds to 24.35 ms with 5 percent widths and are saved to disk.

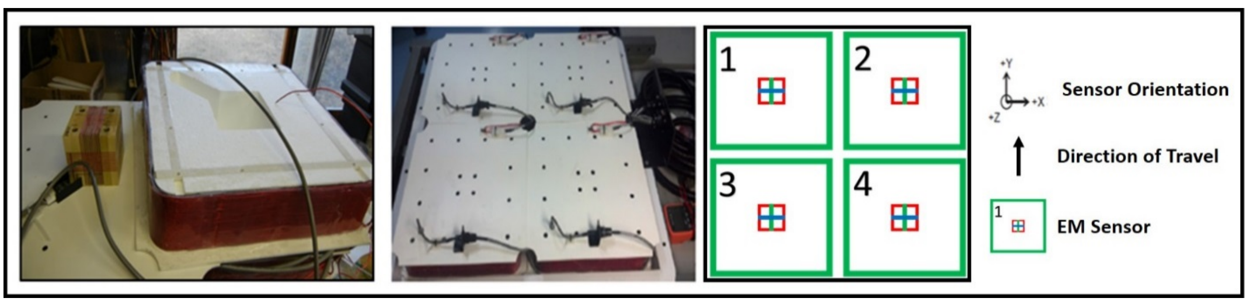

Figure 2-1. Single-element TEMTADS Three-axis Receiver Transmit Coil (Left Photo), Sensor Array (Right Photo), and Schematic Array Diagram

The TEMTADS is a person-portable system that is deployed on a set of standard wheels. This results in a sensor-to-ground offset of approximately 18 cm, or results in a two-person litter mode where the carry height is approximately the same as when deployed in wheel mode. The array structure is fabricated from PVC plastic and Garolite fiberglass. The transmitter electronics and the data acquisition computer are mounted on the operator backpack, a positioning unit is mounted on top of a Garolite fiberglass pole, and an inertial measurement unit (IMU) is mounted above the array. The TEMTADS can be operated in two modes: dynamic and cued. Data collection is controlled in dynamic mode using G&G Science's EM3D application suite. In cued mode, the locations of previously identified anomalies are flagged and surveyed with static measurements directly over the flag location.

Custom software written by the NRL is used to control the cued data acquisition. Both sets of software are accessed through a remote desktop on a computer tablet.

2.1.2 Positioning Systems

Positioning data were recorded using a RTK GPS at NBAFS and a RTS at TOAR. Different positioning systems were necessary because of the difference in tree cover at the two sites.

The survey area at NBAFS was open (trees were present along the edges of the survey) allowing positional data to be recorded using a Trimble R8 receiver operating in RTK mode. The GPS receiver was centered over the TEMTADS sensor. **Figure 2-2** shows a portion of the survey area (left photograph) and the sensor with the GPS antenna set-up for surveying (right photograph). Real-time corrections were provided using a local base station consisting of a separate R8 receiver and Trimble TDL450 external radio. The base station and external radio set-up are shown on **Figure 2-3**. The pitch, roll, and yaw of the system were recorded using an IMU mounted beneath the GPS antenna.

Figure 2-2. NBAFS Survey Area Conditions and TEMTADS with GPS Antenna

Figure 2-3. NBAFS RTK GPS Base Station

At TOAR, site conditions did not permit the reliable use of a RTK GPS positioning system. Positional data were recorded using a Trimble R7 RTS with a MT1000 active prism centered over the TEMTADS sensor. A non-metallic pole was added to the system to raise the height of the prism above the heads of the operators, thus allowing the operators to walk without blocking the prism from the RTS base station. Positional data were logged at a nominal rate of 10 hertz. The pitch, roll, and yaw of the cart were recorded using an IMU mounted beneath the prism. **Figure 2-4** shows the wooded site conditions of the TOAR survey area, the TEMTADS sensor with the MT1000 prism deployed for surveying (left photograph), and the RTS base station (right photograph).

Figure 2-4. TOAR Survey Area Conditions, TEMTADS with MT1000 Prism, and RTK Base Station

2.1.3 Data Acquisition User Interface

At both NBAFS and TOAR, data collection was controlled using a tablet, which wirelessly (IEEE 802.11g) communicated with the data acquisition computer on the operator backpack. The tablet operator also managed field notes and team orienteering functions. Images of the tablet user interface for dynamic and cued data acquisition are shown in **Figure 2-5**.

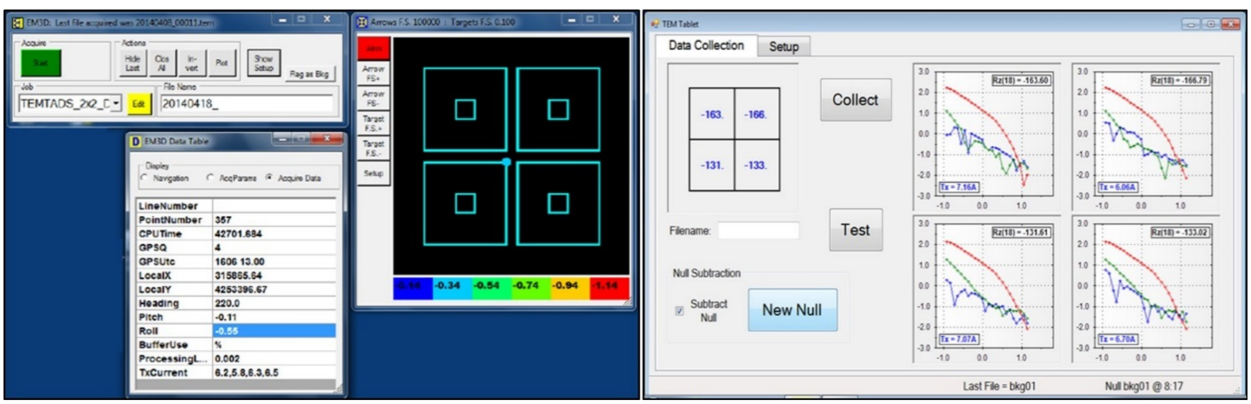

Figure 2-5. Dynamic Data Acquisition Interface (Right) and Cued Data Acquisition Interface (Left)

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Site conditions at NBAFS supported the efficient use and deployment of the TEMTADS sensor in its standard wheel mode. Although the TEMTADS was designed to be used in difficult terrain and in wooded areas that larger systems (e.g., MetalMapper) could not access, it was anticipated that the micro-terrain features at TOAR could result in increased sensor noise levels because of the bouncing and shaking of the array as its skids made contact with the ground surface, rocks, and fallen logs.

Irregular heights because of its being lifted over objects can also decrease sensor sensitivity. In addition, imprecision in the positioning data can result from increased pitch and roll movements exacerbated by increased height of the RTS prism. As a result, one of the objectives of the TOAR demonstration was to determine how well the TEMTADS performs in litter carry mode and to assess the efficacy of this modality with difficult survey conditions.

Another serious limitation of the technology is anomaly density; for all advanced EMI systems there is a limiting anomaly density above which the response of individual targets cannot be separated. Recent developments in multi-source solvers have facilitated improved results within elevated anomaly density areas, although for sites with areas of significant anomaly density the result may still be saturated response areas that cannot be subjected to classification. At TOAR, an exploratory G-858G (magnetometer) survey was conducted to identify areas of suitable density for the demonstration. At NBAFS, one of the overall objectives of the demonstration was to assess the efficacy of the TEMTADS in performing dynamic detection and cued classification at a site known to have a high density of metal and small TOI.

Densely wooded environments are challenging for positioning the TEMTADS sensor. The advantages of using the TEMTADS as a dynamic detector rely upon precise positioning that cannot be achieved using fiducial marks and interpolation. Although RTS systems can be used in wooded environments where the line of sight along the survey transect is disrupted, localized gap-fill surveying requiring multiple base station setups is needed to achieve 100 percent coverage along the transects.

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3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration were designed to provide a basis for evaluating the performance of the TEMTADS with various challenging site conditions. The minimum acceptable criteria were the thresholds used to determine that the system was working properly. Values below this threshold are a potential cause for rejection of the data and require a root cause analysis/corrective action if appropriate (including potential re-collection of data). The nominal success criteria represent the expected achievable threshold. Failure to meet these thresholds requires a discussion in the project report but are not cause for rejection of the data.

To avoid repetition, the specific performance objectives for the demonstration are presented along with the results in Section 6 for NBAFS and Section 7 for TOAR.

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4.0 SITE DESCRIPTION

This section provides a brief summary of the demonstration sites at NBAFS and TOAR. All site information that has immediate bearing on the performance of the TEMTADS is discussed by demonstration area below.

4.1 NBAFS

The NBAFS demonstration site is located within MU705, the Shooting Fields, which is a 115-acre area located in the northwestern portion of NBAFS, New Hampshire (NH). Outside of the active Operations Area the site is used for a variety of recreational activities.

4.1.1 Site Location

The NBAFS is a 2,826-acre site located within the towns of New Boston, Amherst, and Mont Vernon, NH. Outside of the active Operations Area, NBAFS consists of forests, fields, hills, wetlands, and ponds that provide a variety of camping and recreational opportunities. These opportunities are restricted to NBAFS personnel and guests. The Joe English Pond was once the focal point of recreational activities at NBAFS. However, Joe English Pond was closed to all recreational activities in 1998 because of the probable presence of MEC. The land immediately surrounding NBAFS is heavily wooded, rural, and consists primarily of low-density residential areas. There are several active farms in the area surrounding NBAFS, most of them situated on land adjacent to Chestnut Hill Road. The population and housing growth in the three surrounding communities is apparent from recent housing construction on the land surrounding NBAFS. The Joe English Conservation Area, Amherst, NH, is located immediately southeast of NBAFS.

NBAFS was nominated to the National Register of Historic Places in 2004 as the ‘New Boston Air Force Station Archaeological District’. When it was nominated, the district included over 50 contributing properties representing thousands of years of human use. The district includes seven pre-contact sites of unknown cultural affiliation, including three small habitation areas and four isolated finds, 41 historic properties (ca. 1780-1940), and eight properties associated with the WWII- and Cold War-era use of the location by the U.S. military (ca. 1942-1956). The contributing properties include a wide range of resource types associated with cultural and social history, land use, and architecture important to the local, regional, state, and national history.

The ESTCP study was conducted on a subset of the MU705, the Shooting Fields, which is a 115-acre area located in the northwestern portion of NBAFS, directly southeast of Joe English Hill. The boundaries of MU705 were defined based largely on the 1995 UXO clearance boundary data obtained from NBAFS Geographic Information System. MU705 is a moderately sloped area with portions heavily forested with dense brush. **Figure 4-1** provides a location map for the NBAFS demonstration site. Photographs from the site are provided as **Figure 4-2**.

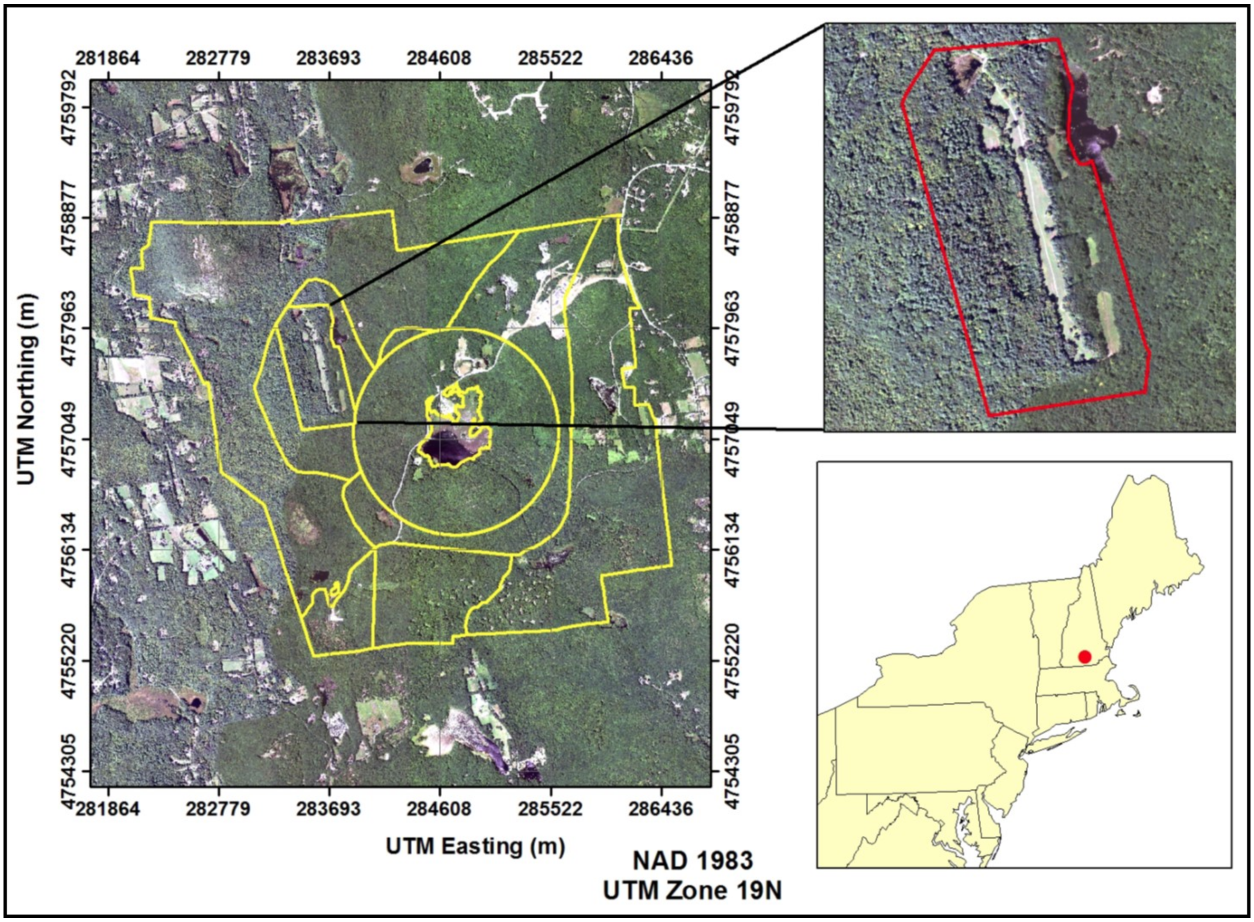


Figure 4-1. NBAFS Location Map

Figure 4-2. NBAFS Site Photographs

The NBAFS site was chosen by ESTCP as one in a series of sites for demonstration of the classification process. Sites including this one provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions. This site presented the opportunity to demonstrate performance against 20-mm projectiles and high anomaly densities. The general site setup and grid system where dynamic TEMTADS surveys were performed at the site are shown on **Figure 4-3**. Approximately 6.1 acres were mapped using the sensor in dynamic mode. Cued investigation was subsequently performed on a subset area of the site because the high density of geophysical anomalies detected in the subsurface far exceeded the budgeted scope for cued investigations (1,500 anomalies).

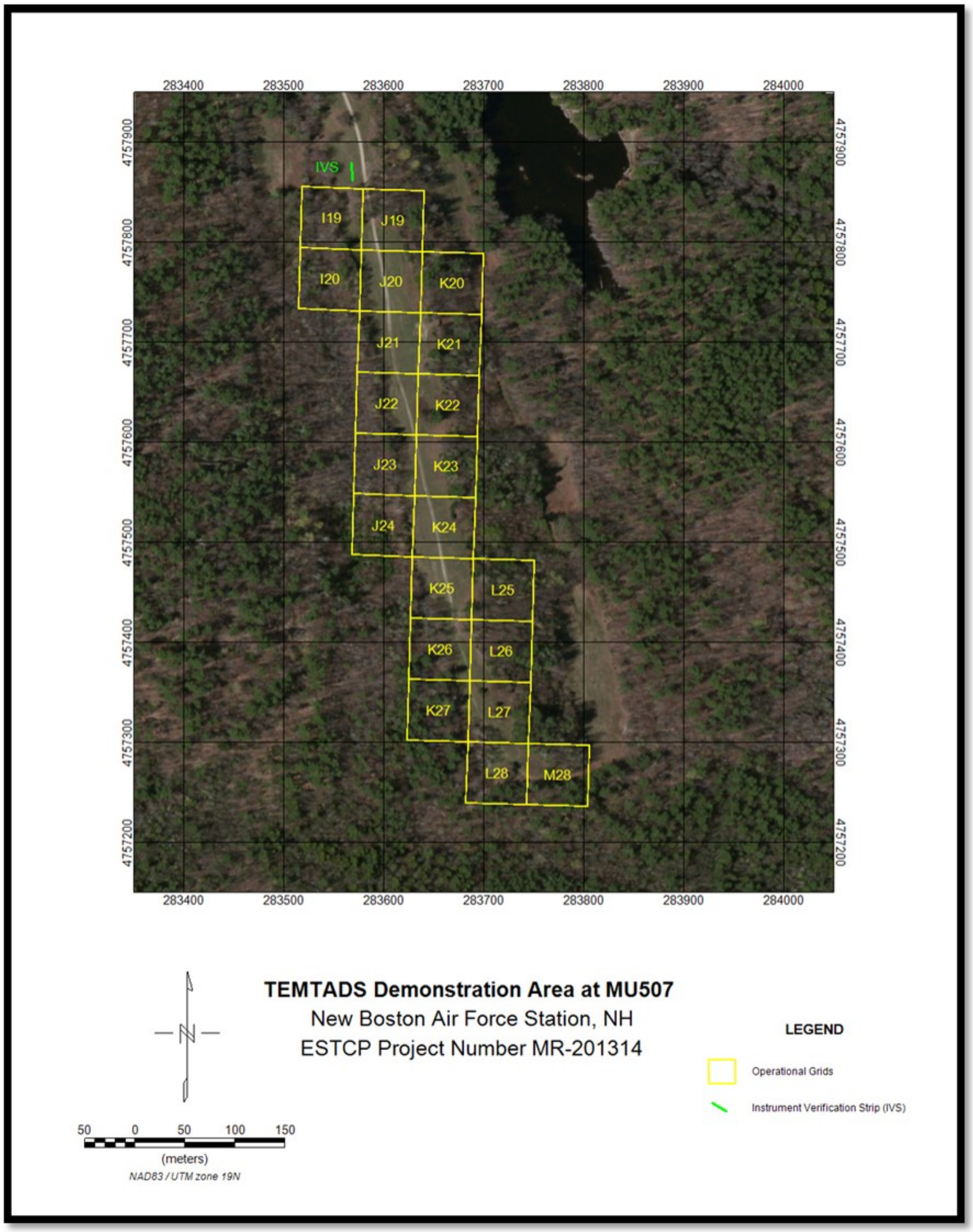


Figure 4-3. NBAFS MU507 Selected Demonstration Grids

4.1.2 Brief Site History

In the fall of 1941, the Federal Government acquired the 2,826 acres comprising the current configuration of NBAFS. This land was used as an active bombing range in support of Grenier Field at nearby Manchester, NH, until 1956. On 1 October 1959, the 6594th Instrumentation Squadron was activated at NBAFS. The squadron was assigned to the 6594th Aerospace Test Wing at Sunnyvale, California, and was a tenant of the 2235th Air Base Group, Grenier Field, where administrative and support facilities were maintained.

Satellite support operations began on 1 April 1960, using van-mounted equipment while permanent buildings were being constructed. By the summer of 1964, dual-satellite tracking, telemetry, and command capabilities were operating in permanent facilities at NBAFS. In March 1972, it was announced that Grenier Field would close in September of that year. All support facilities including supply, transportation, fire protection, and civil engineering were moved to NBAFS.

On 1 October 1979, the 6594th Instrumentation Squadron was re-designated as Detachment 2, Air Force Satellite Control Facility, Air Force Systems Command. On 1 October 1987, Detachment 2, Air Force Satellite Control Facility was re-designated as Detachment 2, 2nd Satellite Tracking Group and ownership was transferred from Air Force Systems Command to Air Force Space Command. On 1 November 1991, Detachment 2, 2nd Satellite Tracking Group was re-designated as the 23rd Space Operations Squadron. NBAFS currently provides launch, operation, and on orbit support for more than 170 Department of Defense satellites. In addition, NBAFS supports NASA missions as well as NATO and other allied nation satellite operations.

NBAFS was used as an active bombing range in support of Grenier Field at nearby Manchester, NH, from the fall of 1941 until 1956. In addition to bombing activities, training and maneuver activities were performed on the property from 1956 until 2002, when the range officially closed.

The ESTCP study area, MU705, was one of the primary bombing/aerial targets used at NBAFS from 1942 to 1956. Unserviceable tanks, trucks, and half-tracks were used as strafing targets for machine guns, 20-mm cannons, and rockets.

4.1.3 Site Geology

The site geology at NBAFS had no practical impact on the technology demonstration.

4.1.4 Munitions Contamination

Munitions suspected to be present at MU705 include:

- 20-mm Projectile, Target Practice
- Practice Rockets, 2.25-inch and 5-inch
- High explosive (HE) Rockets, 5-inch
- Practice Bombs, 3-pound (lb), 4.5-lb, 100-lb, 500-lb, and 1,000-lb
- General Purpose HE Bomb, 100-lb
- HE Depth Bomb, 325-lb and 350-lb

- M69 Incendiary Bomb
- Photoflash Bomb, M46

4.2 TOAR

The TOAR demonstration site is located within MRS-R04A (West) at TOAR FUDS, which is situated within Pennsylvania State Game Lands. The site is used for recreational activities such as camping, hiking, fishing, mountain biking, and snowmobiling. Parts of the MRS are located within a designated natural area open only to passive recreation and hunting.

4.2.1 Site Location

MRS-R04A (West) encompasses approximately 250 acres and is characterized by densely wooded, uneven terrain. **Figure 4-4** shows photos of the existing site conditions taken by CH2M during a site reconnaissance visit on 19 and 20 May 2015. **Figure 4-5** shows the MRS with the operational grid system used by the munitions response (MR) contractor performing work at the site. Each grid square measures 100 feet by 100 feet. This figure also presents an enlarged view of the 11-acre portion of the MRS that had not yet been cleared by the MR contractor and from within which up to 2 acres was selected for the demonstration. Based on historical live-fire training conducted on artillery ranges at TOAR FUDS, and the results of a previously completed remedial investigation, this MRS encompasses an impact area.

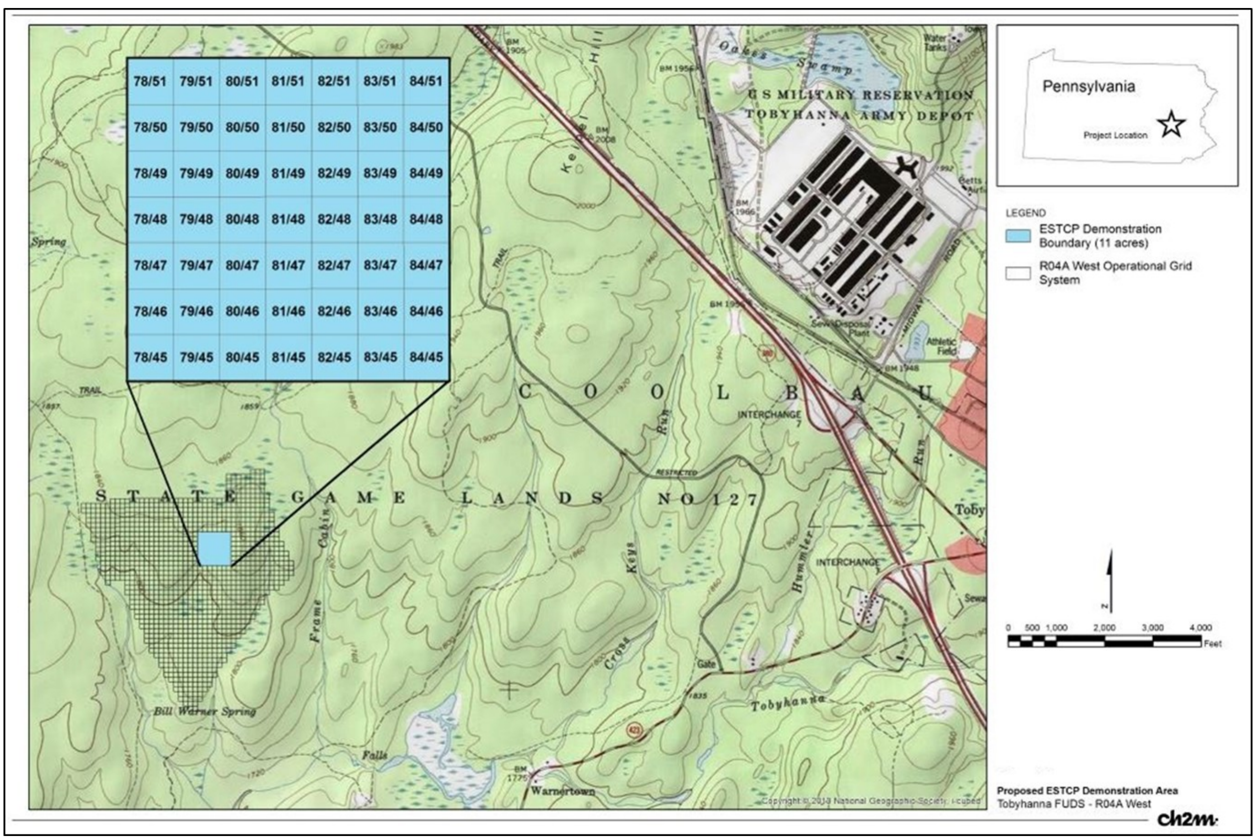


Figure 4-4. TOAR MRS-R04A (West) ESTCP Demonstration Area

Figure 4-5. TOAR Site Condition Photographs

Information that would enable estimation of anomaly densities for the MRS had not been provided; therefore, CH2M performed a digital geophysical mapping survey with a Geometrics G-858G cesium vapor gradiometer along transects extending through the accessible portions of the approximately 11-acre area shown on **Figure 4-4**. The intended nominal transect spacing was 6 meters (m); however, because no vegetation reduction was performed in advance of the G-858G survey, transect spacing and percent coverage was variable across the area. The objective of the survey was to assess relative anomaly densities in order to identify candidate grids for the TEMTADS and MPV demonstrations. Positional data for the G-858G survey were recorded using a Trimble ProXRS differential GPS system with an intended sub-meter horizontal accuracy. A Geometrics G-856 proton precession magnetometer was used as a stationary base station to record ambient magnetic field fluctuations throughout each day of G-858G data collection in order to facilitate evaluation of total field data recorded by each G-858G sensor.

Processing and target selection of the G-858G transect data were performed using the Geosoft Oasis montaj (Geosoft) software platform. Visual Sample Plan (Battelle Memorial Institute, 2015) was used to obtain estimates of anomaly density within the 11-acre area. Transect paths and calculated anomaly densities are shown on **Figure 4-6**. From these data, two grid pairs (78/46–79/46 and 82/47–83/47) were selected for the demonstration. CH2M identified these two sets of grids because they were sufficiently far apart from each other to facilitate concurrent data collection with the TEMTADS and MPV without the risk of the two sensors interfering with each other.

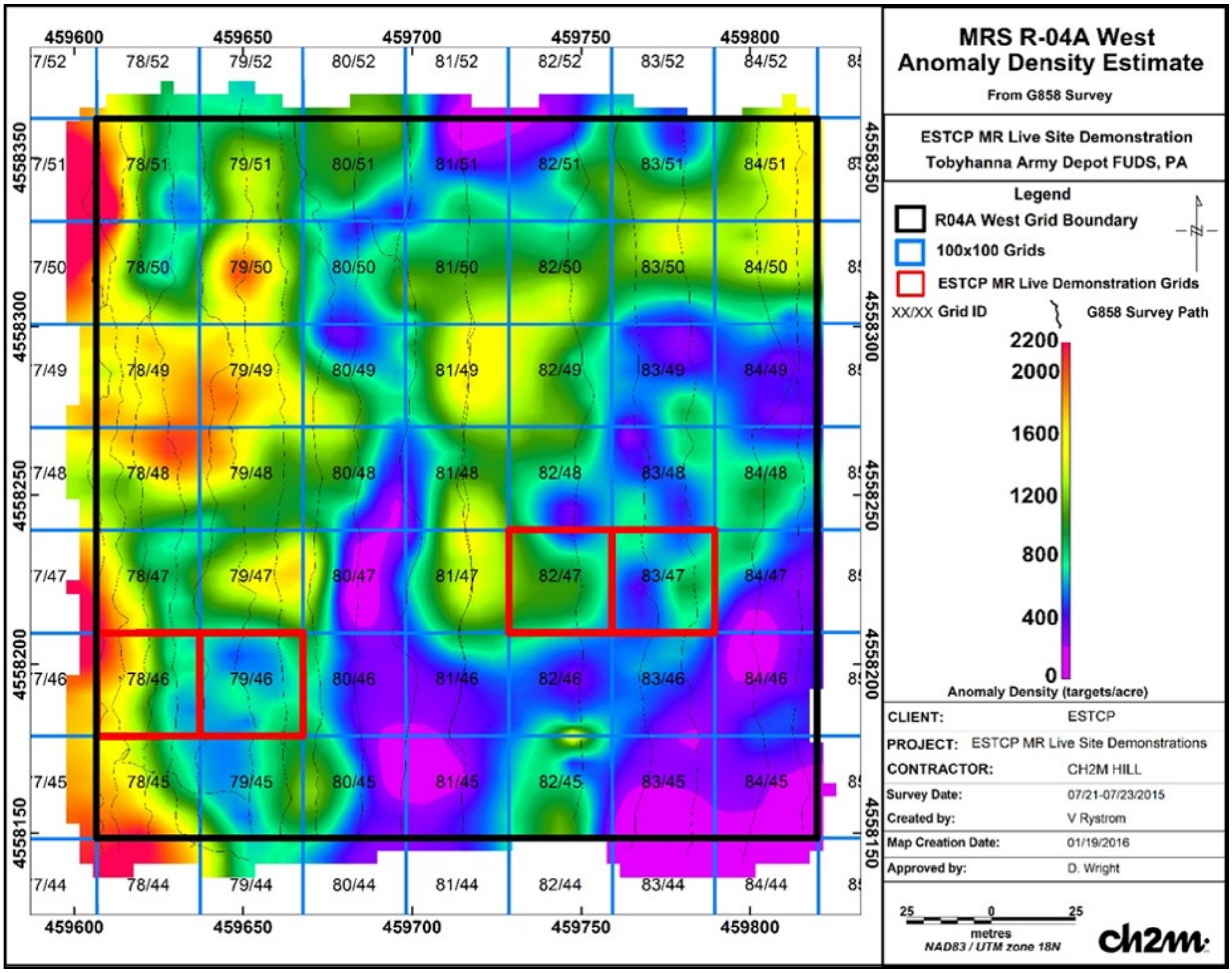


Figure 4-6. TOAR MRS-R04A (West) Anomaly Density Estimates and Selected Demonstration Grids

4.2.2 Brief Site History

TOAR was established as Camp Sumerall when the United States purchased 33 square miles of property in Monroe County in 1909. The facility was used for a variety of missions throughout the years.

The site was first used for machine gun and artillery training during 1913. The Army and National Guard used the facility from 1913 until 1949 for field artillery practice. Camp Sumerall was also used as a training area for tanks from July through October 1918. The ranges were the only areas in Pennsylvania where live cannon fire was permitted from 1919 to 1932. During this timeframe, the rounds were mainly 75-mm French artillery. The range area between Warnertown and Route 611 became a temporary Headquarters Explosives Depot. An estimated 4 million pounds of high explosives were stored from February 1919 through October 1919. Bunkers were constructed in the current State Game Lands 127. The storage designation only lasted 10 months.

4.2.3 Site Geology

The site geology at TOAR had no practical impact on the technology demonstration.

4.2.4 Munitions Contamination

Suspected munitions within MRS-R04A (West) include primarily 75-mm and 155-mm HE and shrapnel projectiles; however, during the remedial investigation conducted within MRS-R04A (West), 37-mm HE projectiles were reportedly recovered along with 75-mm and 155-mm HE projectiles.

5.0 TEST DESIGN

This section provides an overview of the system design and testing conducted during the demonstrations. Sections 5.1 through 5.5 discuss the specific test design elements for both demonstrations, Section 5.6 provides the details for data collection at NBAFS and Section 5.7 for TOAR.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The broad objective of this program was to demonstrate the methodology for the use of classification in the MR process. For both demonstrations, the three key components of this methodology were:

- Dynamic-mode survey for target detection and development of a cued target list
- Static-mode survey for cued target interrogation (data collected for extraction of target parameters such as size, shape, and materials properties) and construction of a ranked anomaly list
- Post-acquisition analysis

Each of the above components was handled separately in this program.

Dynamic detection data were processed and selected anomalies were subsequently investigated through cued interrogation. Individual cued data sets were processed using existing routines in UX- Analyze to extract target parameters.

5.2 SITE PREPARATION

At NBAFS site preparation included vegetation reduction (mowing) of the survey area before the commencement of field activities. A surface clearance of the demonstration area was conducted as part of the Remedial Investigation completed in 2012.

At TOAR, vegetation reduction was performed in the survey area grids where a brush reduction team removed vegetation smaller than 6 inches in diameter. Low branches were cleared to 8 feet above ground to reduce obstruction of the RTS prism; large logs and fallen timber were not removed. CH2M also performed a surface clearance of the selected demonstration grids before collection of dynamic data.

5.3 SYSTEM SPECIFICATION

To avoid repetition, see Section 2 for a detailed description of the overall system including the TEMTADS sensor, platform, positioning systems, and data acquisition system.

5.4 SITE GEODETIC CONTROL INFORMATION

At NBAFS, two first-order survey monuments were established at the site by ESTCP before CH2M operations and were used for all positioning during the project. The monument's labels and coordinates are provided in **Table 5-1**.

Table 5-1. NBAFS Geodetic Control Locations

ID	Easting (m) NAD83/UTM19N	Northing (m) NAD83/UTM19N	Elevation NAVD88 (m)
ESTCP1	283653.23	4757474.53	223.880
ESTCP2	283617.32	4757723.70	217.755

NAD83 = North American Datum of 1983
NADVD88 = North American Vertical Datum of 1988
UTM = Universal Transverse Mercator

At TOAR, two control monuments were used by the professional land surveyor (PLS), GeoMetrics GPS, Inc., to gain control of the site: #7 MON FP5 and #31 IRC FP5 AZ. New control stakes were set for the work area grids known as MRS-RO4A West, grids 78/46–79/46 and 82/47–83/47. These points were set by establishing a pair of RTK GPS control points in the open (no tree canopy), outside of the grid areas, running a conventional survey traverse to the grids, then rough-checking the traverse point position with GPS under the heavy tree canopy. Because of the heavy woods and terrain, control point recover sheets were not produced. From these control points 16 additional control points were established within the four grids. Their labels and coordinates are provided in **Table 5-2**.

Table 5-2. TOAR Geodetic Control Locations

ID	Easting (m) NAD83/UTM18 N	Northing (m) NAD83/UTM18 N	Elevation NAVD88 (m)
1000	459500.8	4558192.63	557.831
1001	459543.96	4558291.43	559.57
1002	459576.81	4558229.49	557.356
1003	459631.14	4558194.27	554.828
1004	459736.93	4558215.96	557.885
1010	459612.62	4558212.64	555.64
1011	459642.42	4558175.84	554.351
1012	459668.17	4558209.79	555.821
1013	459637.54	4558211.29	555.246
1014	459731.49	4558208.47	558.007
1015	459750.17	4558244.65	557.887
1016	459791.55	4558239.09	560.63
1017	459779.14	4558208.38	560.294
1018	459728.9	4558227	557.984
1019	459609.2	4558176	554.539
1020	459731.4	4558241	557.627
1021	459761.3	4558225	558.549
1022	459760.8	4558209	558.837

5.5 SEEDING

At NBAFS, CH2M placed 110 seeds within the demonstration site area in accordance with the parameters laid out in the ESTCP Live Site Demonstration Seeding Plan (ESTCP, 2013). All seed locations were blind to data collection and analysis personnel. Each flagged location was swept with a Schonstedt analog magnetometer to ensure anomaly avoidance (for safety) and a clean area for emplacement. A hole was dug using a 'plug' technique (removing a 'plug' of topsoil for replacement upon filling the hole) to hide any visual indications of seed placement. Seeds were placed at the locations and depths provided by the ESTCP Program office. Physical characteristics of each seed were recorded onto a whiteboard and placed alongside the excavated hole and photographed and the PLS recorded the locations of the seeds using a RTK GPS. A comprehensive list of seed locations and burial information, including associated photographs, was provided to the ESTCP Program Office.

At TOAR, after vegetation reduction and before conducting the dynamic TEMTADS and MPV surveys, CH2M seeded the selected demonstration grids. CH2M UXO personnel practicing anomaly avoidance buried 20 seed items consisting of industry standard objects (ISOs). ISOs are commonly available pipe sections that have been well-characterized through data measurements and modeling. A combination of small schedule 80 ISOs (diameter = 1.315 inches, length = 4 inches) and medium schedule 40 ISOs (diameter = 2.375 inches, length = 8 inches) were used and buried between 1 cm and 17 cm. The PLS recorded the locations of the blind seeds at the time of emplacement. All seeds locations were blind to data collection and analysis personnel.

5.6 INSTRUMENT VERIFICATION STRIP AND TRAINING PIT

An IVS was established at both demonstration sites in a geophysically quiet location proximal to the survey area. The IVS was used for pre-survey and daily verification of proper sensor operation and functionality. A schematic of the IVS at NBAFS is shown as **Figure 5-1** and details of seed items placed in the IVS are listed in **Table 5-3**. A schematic of the IVS at TOAR is shown as **Figure 5-2** and details of seed items placed in the IVS are listed in **Table 5-4**.

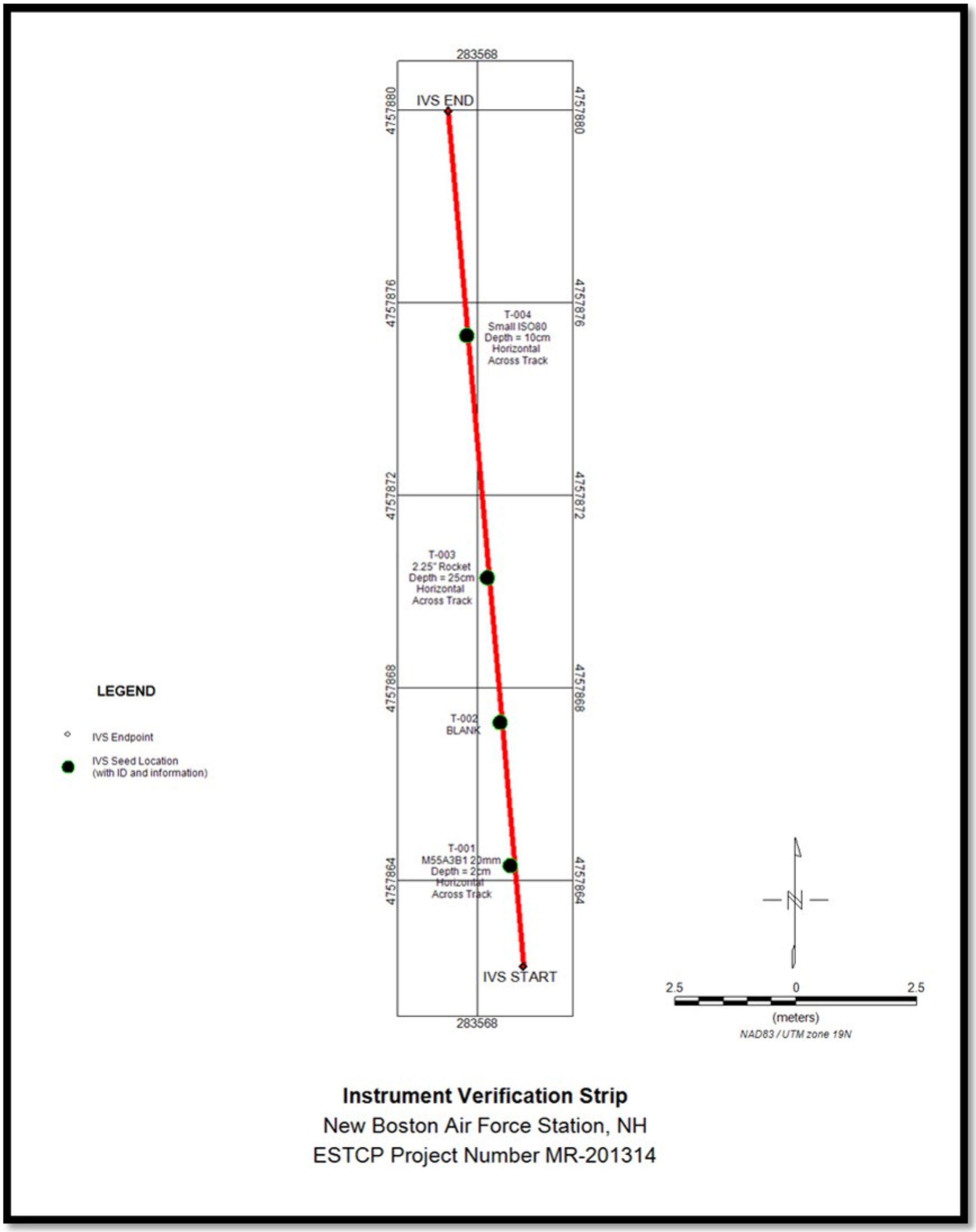


Figure 5-1. NBAFS Schematic of IVS

Table 5-3. NBAFS IVS Construction Details

Item ID	Description	Easting (m)	Northing (m)	Depth (cm)	Inclination	Azimuth (°clockwise from N)
T-001	M55A3B1 20-mm	283568.673	4757864.312	2	Horizontal	Across Track
T-002	Blank Space	283568.46	4757867.286	N/A	N/A	N/A
T-003	2.25-inch Rocket	283568.197	4757870.292	25	Horizontal	Across Track
T-004	Small ISO80	283567.771	4757875.322	10	Horizontal	Across Track

Notes:
Coordinates provided in NAD83, UTM Zone 19 North
N/A = not available

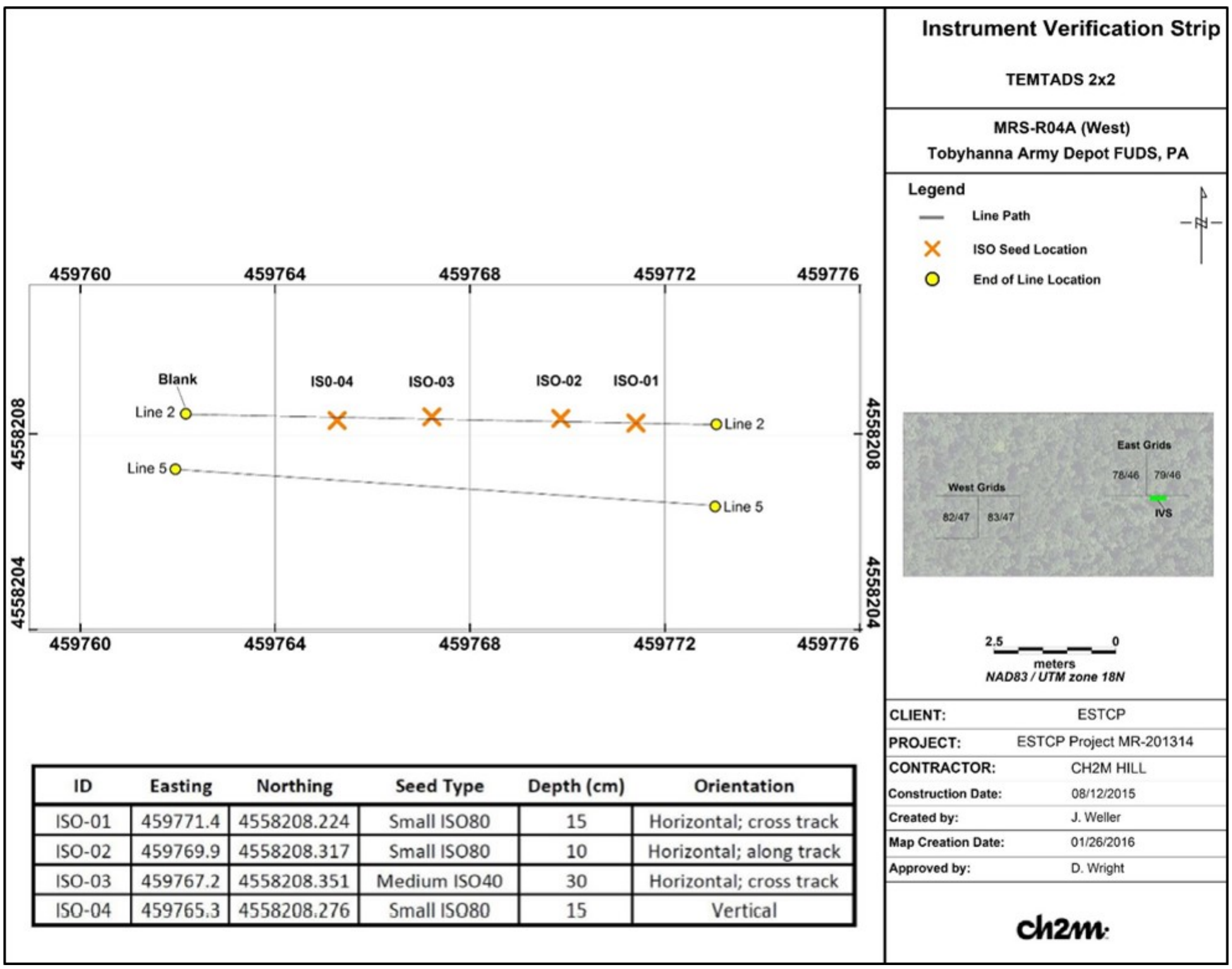


Figure 5-2. TOAR Schematic of IVS

Table 5-4. TOAR IVS Construction Details

Item ID	Description	Easting (m)	Northing (m)	Depth (cm)	Inclination	Azimuth
ISO-1	Small ISO80	459771.40	4558208.22	15	Horizontal	Across Track
ISO-2	Small ISO80	459769.86	4558208.31	10	Horizontal	Along Track

Notes:
Coordinates provided in NAD83, UTM Zone 18 North

At NBAFS, a test pit and test stand were established adjacent to the IVS. These were used to collect signatures of a subset of TOI expected to be found at the site. Items for which static test data were collected are detailed in **Table 5-5**. The data from these measurements were added to the UX-Analyze (UXA) library used for the cued data analysis. No test pit data were collected at TOAR.

Table 5-5. NBAFS Test Stand Items and Orientations

Item ID	Depths (cm)	Orientations
Small ISO80	2, 10, 20, 30	Horizontal, Vertical, 45°
20-mm ATC Projectile	2, 5	Horizontal, Vertical, 45°
2.25-inch Rocket	2, 5	Horizontal, Vertical, 45°
2-inch x 1/2-inch Pipe Nipple with Cap (20-mm surrogate)	5, 10, 15	Horizontal, Vertical, 45°
20-mm Shell Casing	5, 10	Horizontal, Vertical, 45°
Ground Signal Flare	5, 10, 15	Horizontal, Vertical, 45°
M102A1 Fuze	15	Horizontal, Vertical, 45°
M83 Smoke Grenade	10, 15	Horizontal, Vertical
M8 Practice Land Mine	10, 15	Horizontal, Vertical
M120 Fuze	10, 15, 20	Horizontal, Vertical
M103 Fuze	15, 20	Horizontal, Vertical
3-1/2-inch Rocket Warhead, Motor and Fuze	20	Horizontal
3-1/2-inch Rocket Warhead	15, 20	Horizontal, Vertical, 45°
3-1/2-inch Rocket Motor and Fuze	15	Horizontal, Vertical, 45°

5.7 SENSOR CALIBRATION

The TEMTADS sensors used for both demonstrations were calibrated during the initial commissioning of the system at the NRL facility at Blossom Point, Maryland. The system calibration was verified on a regular basis via function tests and daily IVS surveys. The function tests involve measurement of the system response to an ISO placed in a known location relative to the sensor. Function tests were performed a minimum of twice per day to verify the proper operation of all of the sensor transmit and receive components. Results of the function tests and IVS surveys are provided in the discussion of quality control (QC) testing in Section 6 and Section 7 for NBAFS and TOAR respectively.

5.8 DATA COLLECTION

For clear presentation of data collection activities, this discussion is presented in two general sections corresponding to the two demonstration areas. The summary of data collection events at NBAFS is presented first followed by TOAR.

5.8.1 NBAFS

5.8.1.1 Dynamic Data Collection (Mappping Survey)

In the first phase of the demonstration, the TEMTADS was operated in dynamic (mapping) mode in order to generate a detection map and target list. Mapping was performed over approximately 6.1 acres within the survey area at MU705. The dynamic detection survey took place over the course of 11 survey days during the time period from 18 July to 14 August 2013 (during this time period there were a number of no-collection days because of equipment failures as well as weather delays and non-worked weekends). The positions of each measurement were determined using a RTK GPS antenna mounted at the center of the array, coil geometry relative to the GPS antenna, and the platform attitude (pitch, roll, and yaw) derived from the IMU. Data were acquired along a series of parallel transects with a 60 cm (nominal) line spacing. This spacing was designed to provide overlap coverage of 20 cm to reduce the chance of data gaps. **Figure 5-3** shows a mosaic of the data collected at the site.

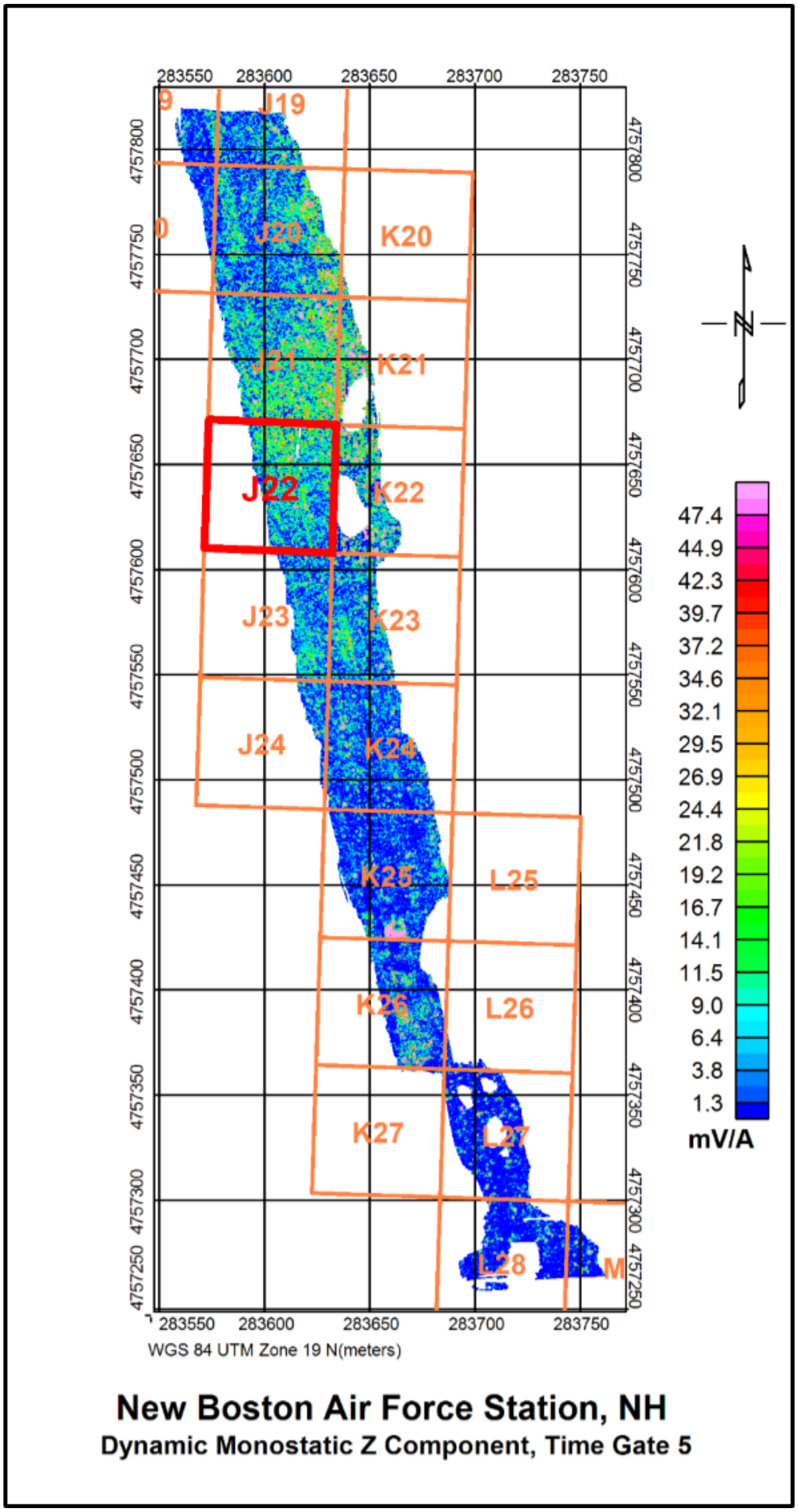


Figure 5-3. NBAFS Dynamic Survey Data Collection and Location of Grid Selected for Cued Survey (J22)

5.8.1.2 Dynamic Data Quality Control

Throughout the course of the dynamic detection survey, the TEMTADS system was tested at the IVS on a twice daily basis to verify proper system operation. In order to measure precision of the system, ongoing analysis was performed on the IVS detection results, with each successive day's results compared to the averaged results of all previous IVS surveys for detection offset and amplitude response of each seed item.

The positions were derived from the dynamic monostatic, Z-component response amplitude using Geosoft's automatic peak picking algorithm. **Figure 5-4** presents the position errors (relative to the ground truth) for each of the IVS items. The errors are within the stated objective of 0.2 m (objectives are presented in Section 6 for NBAFS).

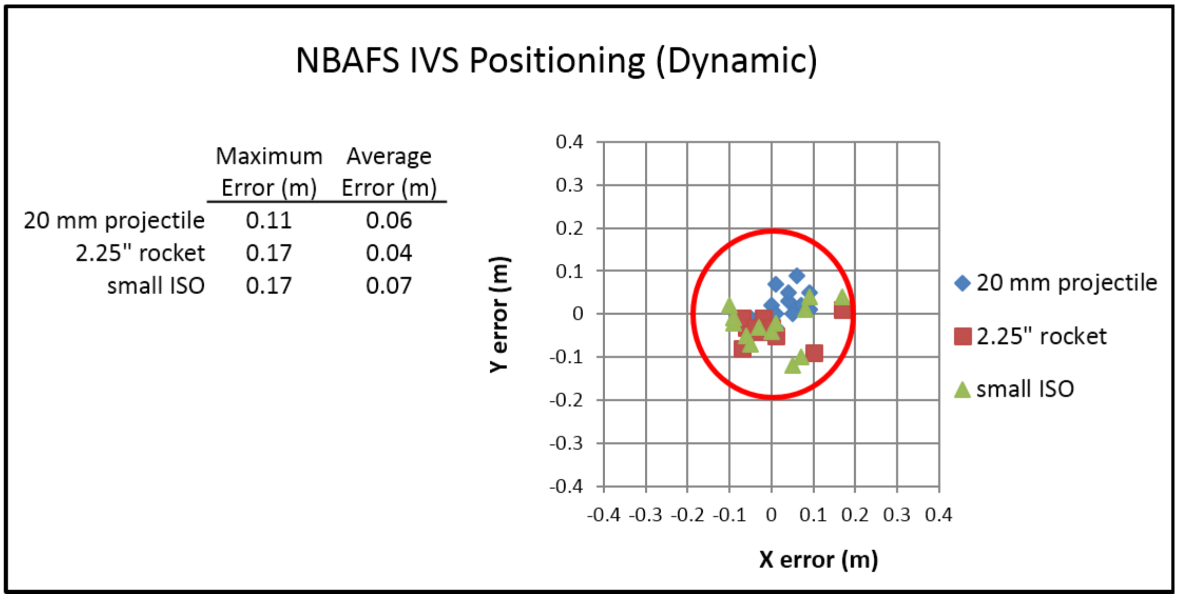


Figure 5-4. NBAFS Dynamic IVS Survey Positioning Results

The response amplitude values were also derived using the automatic peak detection algorithm and are presented in **Figure 5-5**. The variability of these values were within the stated objective of 20 percent root mean square (RMS).

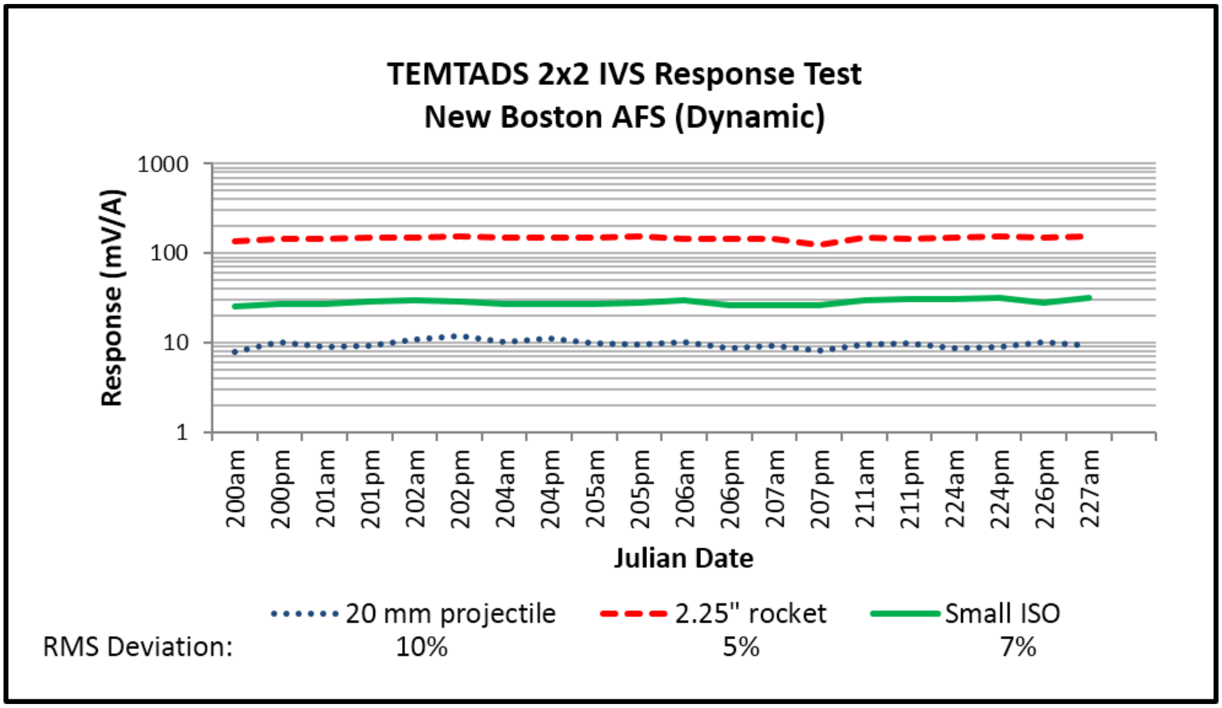


Figure 5-5. NBAFS Dynamic IVS Survey Response Amplitude Results

In addition to the daily IVS measurements, the functionality of the TEMTADS sensor was assessed daily using a system 'function test' whereby the system response was challenged by placing an ISO, 1.5-inch x 4-inch, schedule 80 thickness pipe nipple (small ISO) on the top of the array housing. The function test results are presented on **Figure 5-6**.

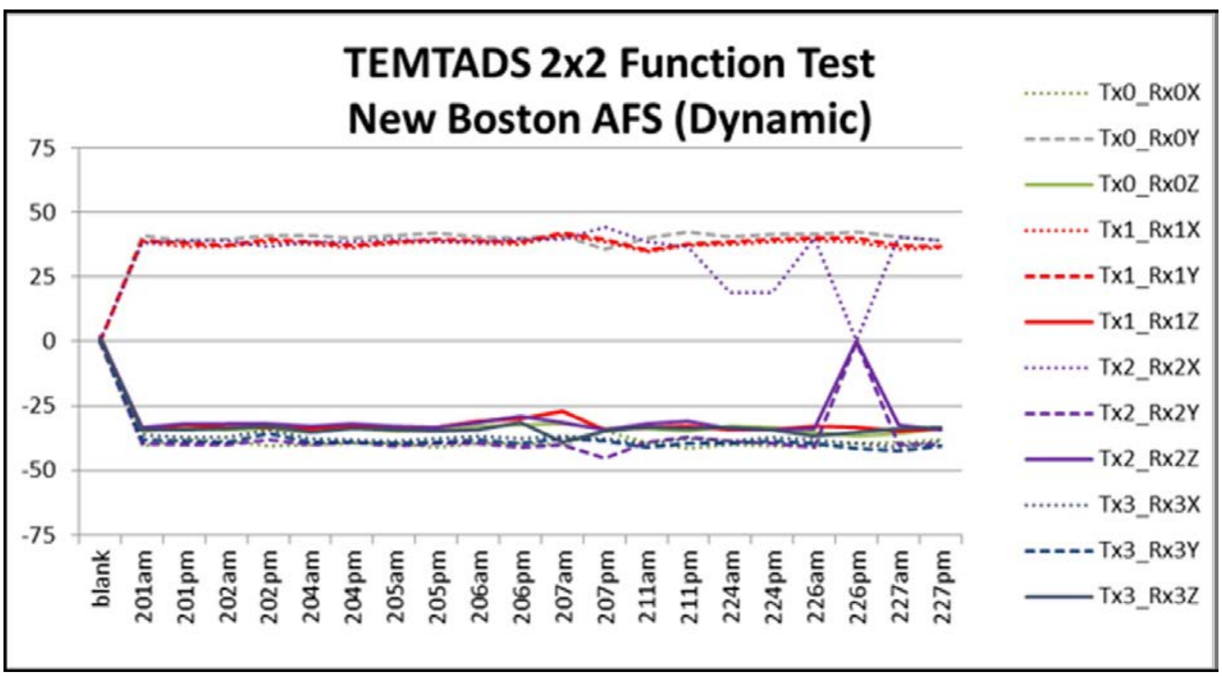


Figure 5-6. NBAFS Dynamic Survey Sensor Function Test Results

These tests identified a failure of the Rx2X coil on Julian Day (JD) 224 (August 12) and failures of the Rx2 cube (X, Y, and Z components) coil on JD 226 (August 14). The affected data were noted in the data delivery package. The decision was made to not re-acquire data from these dates because the effect on the results was determined to be minimal.

5.8.1.3 Dynamic Data Processing and Analysis

The raw instrument data files comprised of raw sensor data, RTK GPS data, and IMU measurement data converted to comma separated values (*.csv) format using NRL's ConvertTEMTADS data conversion application for import into Geosoft's UXA advanced analysis software environment. The *.csv file contains the sensor data merged with the RTK GPS and IMU data providing georeferenced positions for each TEMTADS transmit/receive (Tx/Rx) combination measurement.

The dynamic detection was performed using the amplitude response of the monostatic, vertical component measurements only. This approach is analogous to standard Geonics EM61-MK2 detection surveys with the main difference being that the data are much more dense and precise, providing a much higher resolution data set. Dynamic detection data were imported into the Geosoft UXA module for processing and analysis. Individual sensor data were assigned coordinates based on sensor offset and IMU data relative to the center mounted RTK GPS location. Positioned data were then exported to a located sensor database for data levelling and target selection.

Dynamic detection data were levelled by deriving a background model (comprised of long wavelength signals because of spatially stable soil response and sensor 'zero level' drift) and subtracting this model from the raw data to derive a levelled data set. Because of the anomaly density encountered, typical demedian filters used to derive the background model were not appropriate; as a result, the model was derived using a deminimum filter where the minimum over a large moving window is calculated and then low-pass filtered to remove high frequency artifacts. **Figure 5-7** shows example results of both filters on the raw data.

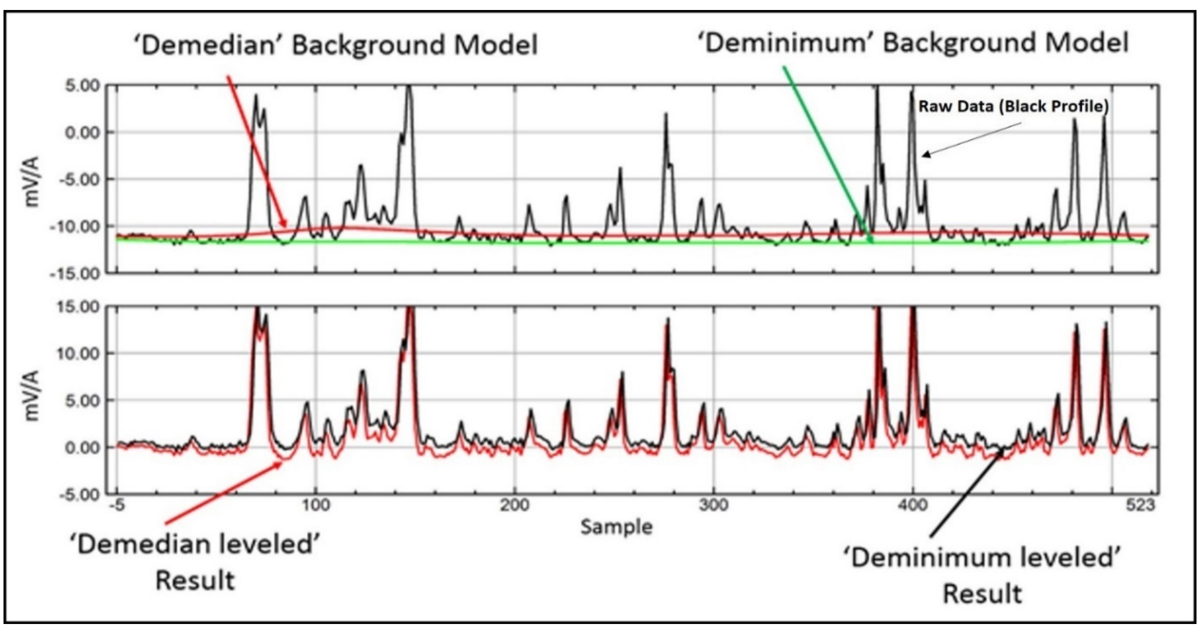


Figure 5-7. NBAFS Dynamic Survey Background Removal

The final, leveled data for each grid were interpolated to grid nodes evenly spaced at 0.05 m using Geosoft's minimum curvature gridding routine. The interpolated Geosoft grid (GRD) files were mosaicked to create a full site GRD file from which anomaly selection was performed.

CH2M provided raw and preprocessed data to the ESTCP Program Office for archiving in the form of *.tem (Input template file), *.csv and Geosoft format databases (*.gdb). In consultation with the Program Office, CH2M identified anomalies in the MU507 dynamic detection dataset. Response amplitude anomalies were selected from the full site GRD using the Geosoft Blakely grid peak detection algorithm. The cut-off threshold was 2.3 millivolts per ampere (mV/A). All anomaly selections were manually reviewed by the processing geophysicist and manual additions or deletions were performed where required. The threshold was validated by analyzing dynamic data collected over items buried in the test pit before the dynamic survey of the demonstration area. The test pit items included 20-mm projectiles (the smallest TOI expected at the site) at various depths and orientations to determine relevant system response values. Site- and system-specific noise information derived from sample survey data were used to validate the proposed anomaly selection amplitude threshold.

5.8.1.4 Cued Data Collection (Static Survey)

After collection and analysis of the dynamic TEMTADS data were complete, the ESTCP Program Office selected a subset of 1,500 anomalies (out of a total of 18,373 anomalies detected by the dynamic survey) for cued interrogation. This down-selection was made to keep the project within its original scope (the anomaly density was an order of magnitude higher that was originally anticipated). The selected anomalies were located within Grid J22 (**Figure 5-8**). Most of the anomalies were within the region located west of the road and east of the forested region (the edge of the survey area). A small number of anomalies were located east of the road – these were selected primarily to include some blind seeds that otherwise would not be have been investigated.

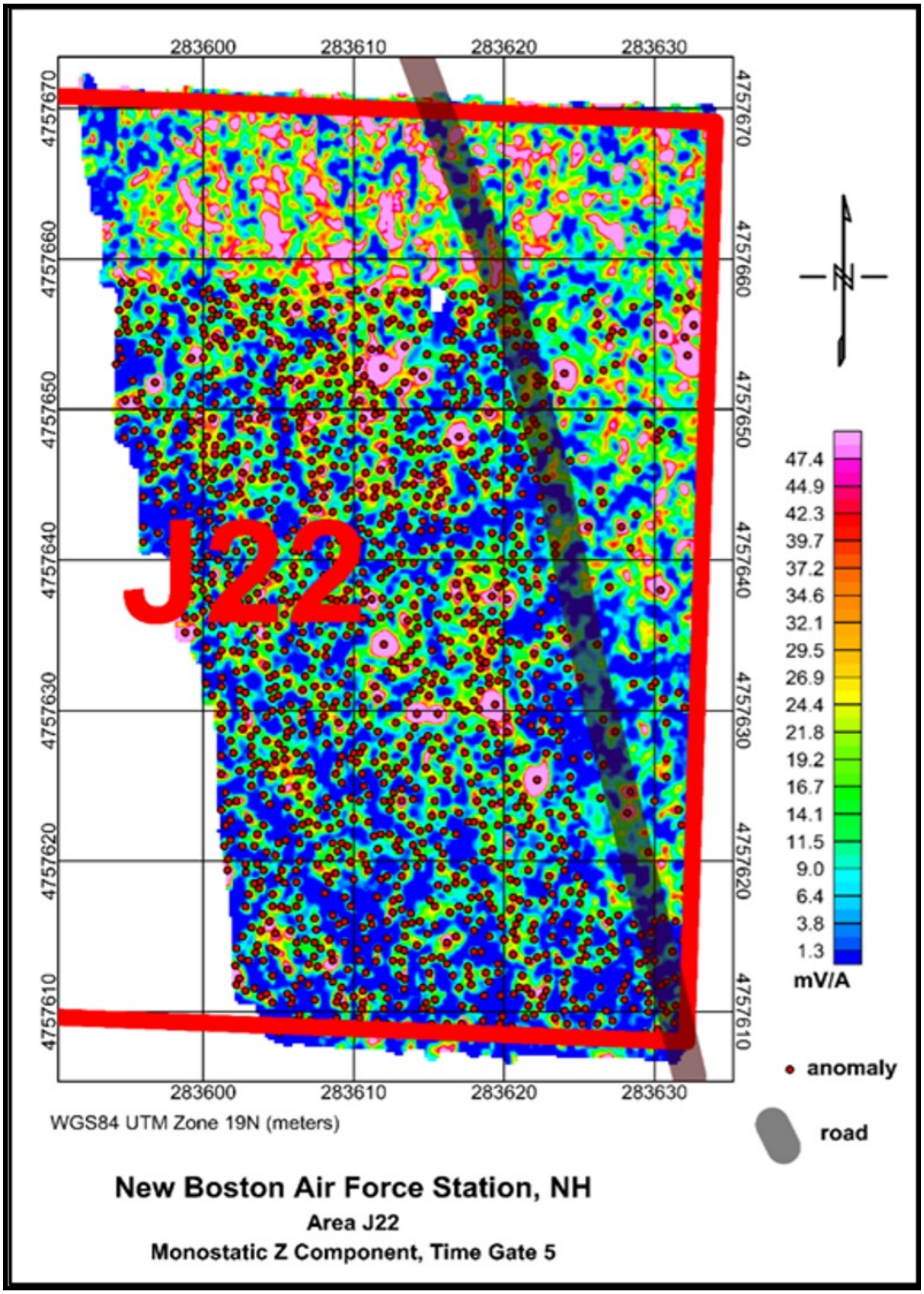


Figure 5-8. NBAFS Anomalies Selected for Cued Interrogation – Grid J22

Cued surveys were performed with the TEMTADS over the course of 23 days from 1 August (JD 213) to 23 August (JD 235), 2013. Data were recorded electronically as collected on the TEMTADS backpack data acquisition computer hard drive. The collected data were copied and backed up daily onto removable media and data were transferred daily to the data analyst for QC/ analysis.

5.8.1.5 Cued Data Quality Control

The QC implemented throughout the cued data acquisition included the following:

- IVS measurements
- Function tests
- Transmit current and receiver decay monitoring
- Field inversion monitoring
- Recollection where horizontal target location was offset by more than 40 cm

Throughout the course of the cued data acquisition, the TEMTADS system was tested at the IVS on a twice daily basis to verify sensor functionality. The daily IVS measurements were inverted and the extrinsic parameter (source position) and intrinsic parameter (source betas) results were monitored and recorded. These results are presented in **Figure 5-9** and **Figure 5-10**, respectively. The values obtained were within the stated limits, with the exception of one of the IVS positions. On the final measurement of 8 August (JD 220) the GPS base station battery failed, resulting in an inaccurate position location for the last of the three emplaced items. Because this failure happened after the day's data collection, it had no adverse implications for the usability of the day's data.

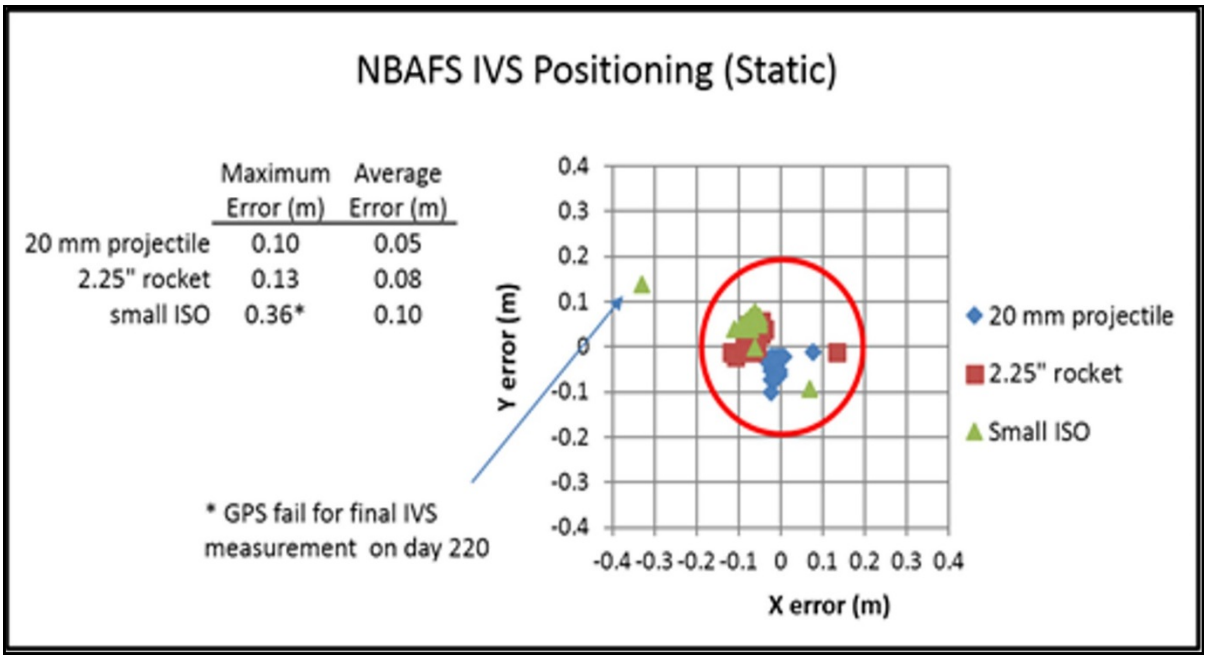


Figure 5-9. NBAFS Cued Data IVS Dipole Fit Position Results

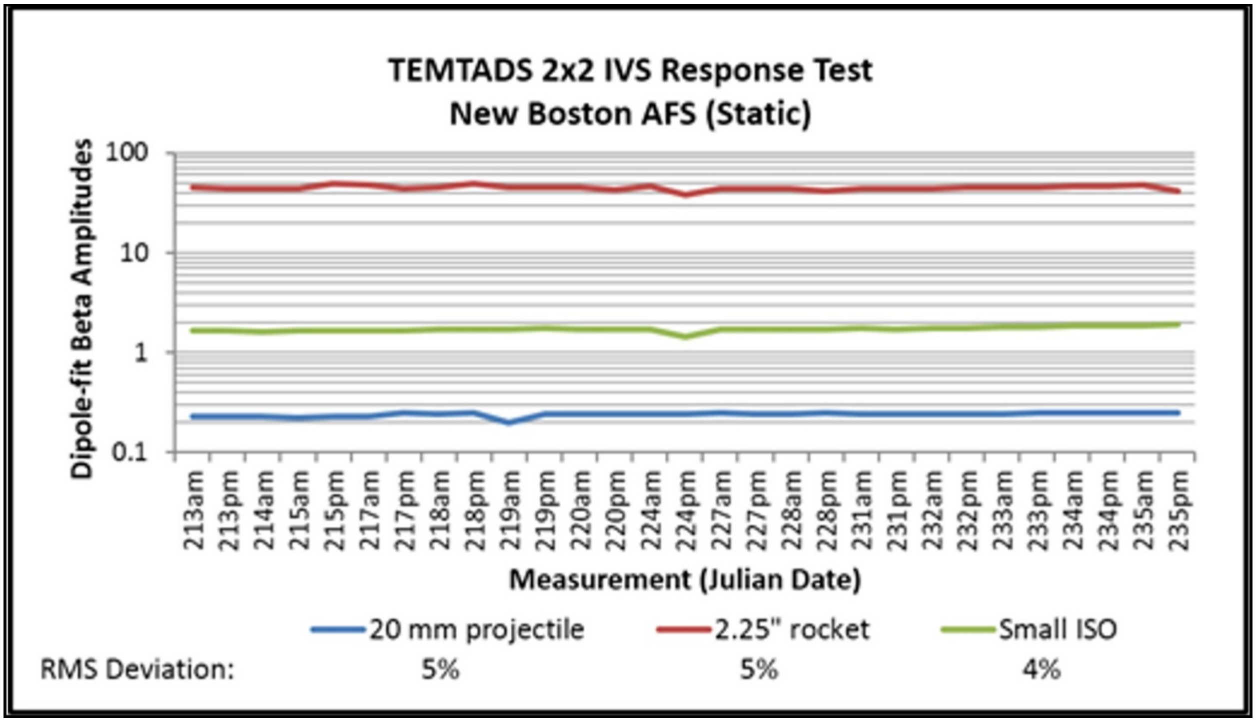


Figure 5-10. NBAFS Cued Data Dipole Fit β Amplitude Results

In addition to the twice-daily IVS, in-field sensor functionality tests were performed throughout each survey day to confirm that the TEMTADS system components were functioning within project specifications. Sensor function tests were performed during each background data collection event. The sensor function test results are shown on **Figure 5-11**. These tests identified a failure of the Rx2X coil on JD 224 and failures of the Rx2Z coil on JDs 232 and 234-235 (11, 13, 14 August 2013).

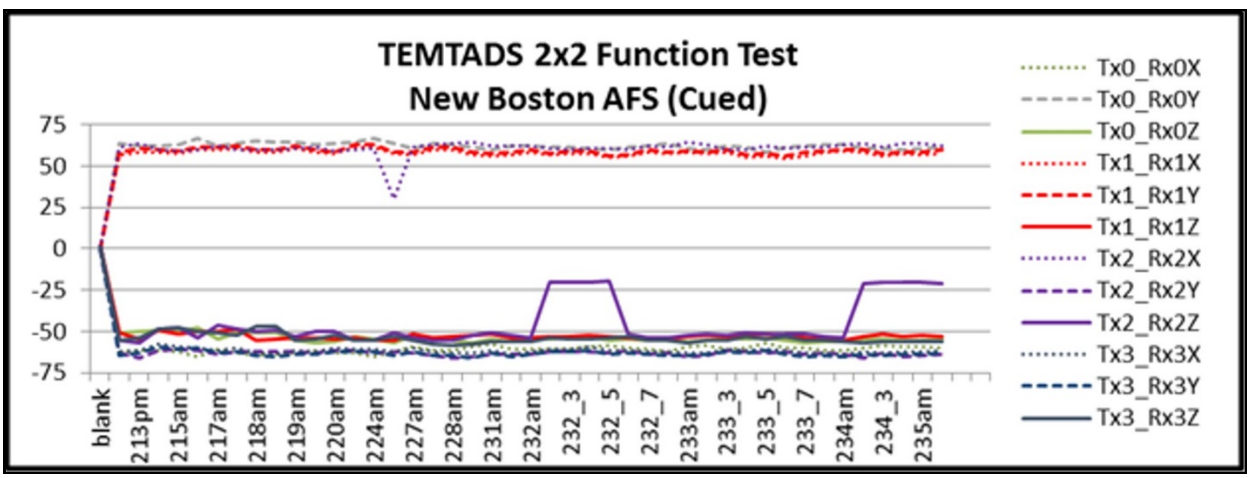


Figure 5-11. NBAFS Cued Data Function Test Results

The effect of the missing data was tested and assumed to be minimal as long as the failed data were rejected from the inversion. This is illustrated by **Figure 5-12**. This figure presents inversion results for a 20-mm target located at 5 positions under the sensor (center and under each coil) with the Rx2Z coil inoperable. On the top row the bad data are included in the inversion and corrupt the inversion results as evidenced by the lower library match values. On the bottom row the Rx2Z data are excluded from the inversion and the inversion results are accurate. The affected data were noted in the data delivery package.

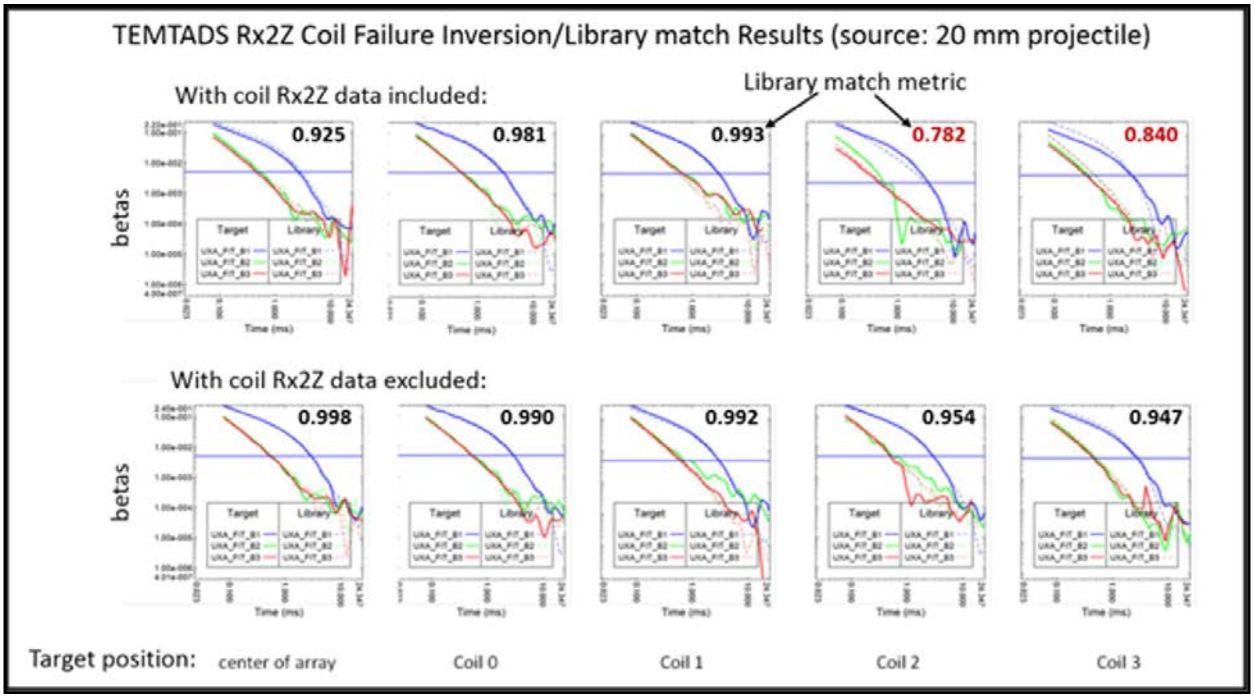


Figure 5-12. NBAFS Effect of Missing Rx2Z on Inversion/Classification Results for a 20-mm Projectile

5.8.1.6 Cued Data Processing and Post-acquisition Analysis

Static data points acquired with the TEMTADS platform located over each of the targets identified using the processes described above were analyzed to extract target-specific parameters. The general processing flow is described in the following steps:

1. Target Association: cued measurements are associated with a particular target from the cued target list
2. Feature Selection: statistical analyses are performed to determine target features
3. Library Matching: target polarization curves extracted for each target are matched to a library of munitions known to exist in the area of interest
4. Analyst Calibration Digs: used to determine the source of any identified clusters of ‘like signatures’ as well as to inform the analyst with respect to the placement of decision thresholds in the prioritized list

5. Prioritized Target List Assembly: final AGC determinations on the set of cued targets and assembly of a final prioritized dig list

Cued data were imported into the Geosoft UXA module for data QC and inversion modeling. The data were levelled using background data collected at frequent time intervals over a nearby anomaly-free background location. The measurements used for background correction were reviewed for variability and to identify any outliers which may correspond to measurements over subsurface metal. To minimize errors in the background removal process, spatial and temporal distance between the background and target measurements were minimized.

Parameter estimation was performed using the Geosoft UXA module. Target data were inverted using both single-source and multi-source dipole response models to estimate target parameters. The principle parameters of interest for use in classification of the targets were the three polarizabilities (β1, β2, and β3) estimated for each target by UXA. In addition to estimates for the three βs for each target, an estimated location and depth was also returned by UXA for each target during inversion.

CH2M provided the raw data (e.g. *.tem and *.gps), and digital as well as analog field notes to the ESTCP Program Office for archiving.

5.8.1.7 Analyst Calibration Digs

Upon initial review of the inversion results. A set of targets were selected as analyst calibration digs (ACD). These data would be used to determine the source of any identified clusters of ‘like signatures’ as well as to inform the analyst with respect to the placement of decision thresholds in the prioritized list.

After receipt of the dig results for the requested ACD, the decision was made to abandon attempts to classify the results. More than 40 percent of the ACD resulted in 4 or more discrete objects being found for a given flag location (a retrospective analysis of all of the dig results indicated that 33 percent of the digs resulted in 4 or more discrete objects).

Comparison with the ground truth revealed that the multi-solver inversion routine was not able to consistently extract the correct signatures for the TOI at the site. **Figure 5-13** presents an example of a false positive finding where the derived signatures do not match the recovered sources, resulting in a non-TOI result being classified as a TOI. Although some percentage of false positives are expected, one of the goals of classification is to minimize these (and thus reduce the number of required intrusive investigations). The fact that the inversion results do not accurately represent the actual subsurface items is demonstrated by this figure.

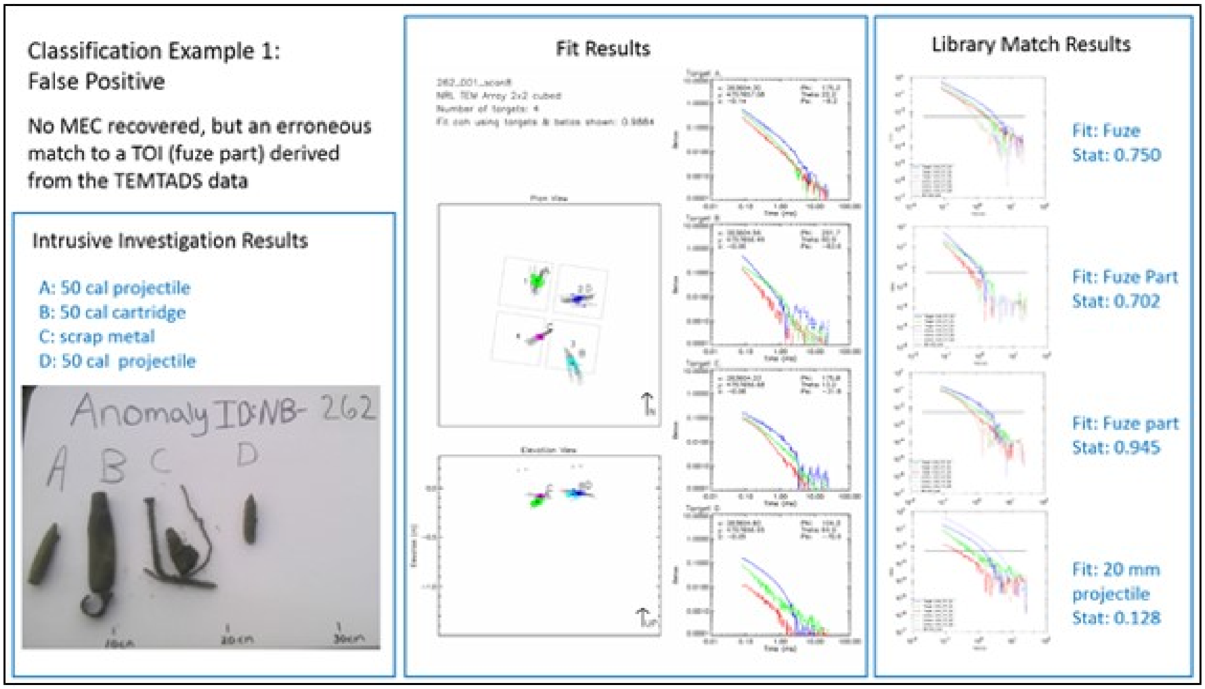


Figure 5-13. NBAFS Example of False Positive Classification Results

False negatives present a much more serious problem. An example of a false negative is shown on **Figure 5-14** where two 20-mm projectiles were recovered, but the inversion results for that flag location did not have a signature that was a good fit to these TOI. These signatures did fit to a 37-mm but with a low fit metric that resulted in a non-TOI classification.

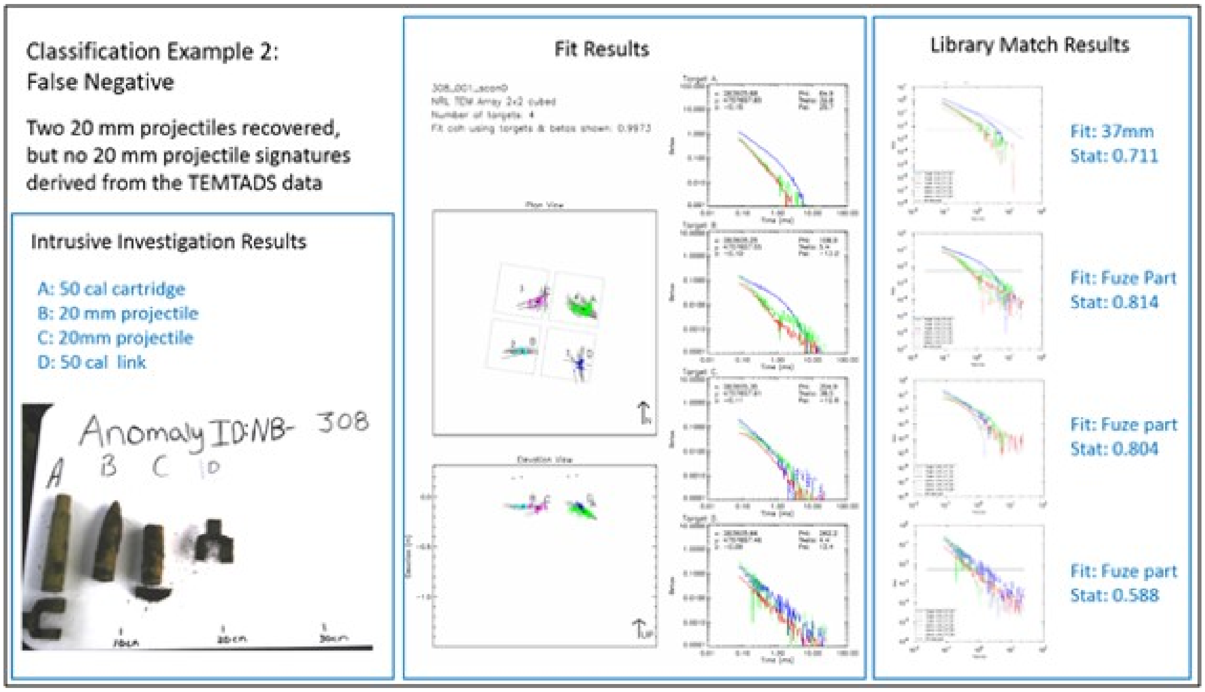


Figure 5-14. Example of 'False Negative' Classification Results

In both of the examples shown, the multi-solver inversion failed to extract signatures consistent with the objects recovered. Qualitative analysis of the results indicates that the multi-solver results become unreliable when 4 or more targets are below the sensor. It bears mention that this was not a quantitative assessment nor does this observation support any generalized conclusions regarding the performance of the multi-solver; this observation only applies for the specific circumstances of this demonstration (sites with larger minimum TOI size might show a different result). Given that 33 percent of the intrusive investigations resulted in three or more recovered items and 70 percent of the excavations resulted in at least one TOI (thus the technology is assumed to be unsuitable at this site), further investigation into the performance of the multi-solver was not undertaken.

5.8.1.8 Classification

After review of the analysis calibration data, an approach that reliably derived accurate intrinsic parameters when there were more than three sources under the sensor was not able to be found. Furthermore, the fact that 70 percent of the intrusive investigations resulted in TOI indicated that submission of a final prioritized list would add no value.

5.8.1.9 Intrusive Activity and Procedures

CH2M performed intrusive operations from 28 August through 24 September 2013. All prosecuted targets were investigated and documented according to the procedures outlined in the *Intrusive Investigation Data Collection Instructions*. These included the following:

- **Reacquisition of targets**. Targets selected for intrusive investigation were reacquired using a Trimble RTK GPS and marked in the field using PVC pin flags.
- **Intrusively investigate the anomaly.** Anomalies were excavated to 30 cm below the expected depth below ground surface, within a 50-cm halo from the marked out anomaly location.
- **Identify recovered item**. All items recovered were inspected by the UXO Safety Officer and Senior UXO Supervisor to ensure that each item was properly identified and properly documented.
- **Munitions Response Site Information Management System (MRSIMS) Data Entry/ Whiteboard and photo**. Field observations of each recovered item were entered into CH2M's MRSIMS field tablets. The exact location and depth of each item was recorded using a Trimble RTK GPS. Required information was written onto a whiteboard and a photo was taken with the item.
- **Bag and label item**. All recovered items were placed in zip-lock bags and labeled.
- **Post-dig clearance**. Before declaring a dig complete, each area was swept with a Schonstedt magnetometer to determine if any additional items remained
- **Backfill hole**. Once the excavation was declared clear, the hole was backfilled to grade.

As NBAFS is included in the National Register of Historic Places, all intrusive investigations were carried out in compliance with the Memorandum of Agreement between the U.S.

Air Force and the New Hampshire Historic Preservation Office (U.S. Air Force, 2013). Archaeological monitoring was performed by a certified archaeologist from CH2M's Archaeology subcontractor, Landmark Archaeology, Inc., and any artifacts of significance that were recovered during intrusive investigations were properly documented and a report provided to the New Hampshire Division of Historic Resources (Landmark Archaeology, Inc., 2014).

5.8.1.10 Deliverables

The following deliverables resulted from the data collection at NBAFS:

1. **Dynamic Detection Data:** Raw and processed dynamic detection data were provided to the ESTCP program office, along with a final target list based on the established detection threshold.
2. **Cued Data:** Raw sensor data (*.tem) and associated GPS/IMU data (*.gps)
3. **Cross-Reference List**: A text readable table that associates TEMTADS filenames with each Target ID and provides any applicable collection notes.

5.8.2 TOAR

5.8.2.1 Dynamic Data Collection (Mappping Survey)

In the first phase of the demonstration, the TEMTADS was operated in dynamic (mapping) mode in order to generate a detection map and target list. Dynamic detection surveys were performed over the course of 11 survey days, from 12 August to 4 September 2015 (during this period there were a number of no-collection days because of equipment failures as well as weather delays and non-worked weekends). There were a total of 8 days of initial data collection and an additional 3 days of effort filling gaps in coverage. The position of each measurement was determined using a RTS prism mounted at the center of the array, coil geometry relative to the RTS prism, and the platform attitude (pitch, roll, and yaw) derived from the IMU. CH2M's field team used ropes and flagging to perform data collection at a line spacing of 50 cm, which provided an overlap coverage of 30 cm to reduce the chance of data gaps. **Figure 5-15** and **Figure 5-16** show mosaics of the data collected at 78/46 and 79/46 (the western) and 82/47 and 83/47 (the eastern) grid sites, respectively.

Dynamic data collection was hindered by the rough terrain (boulders, swamp, felled trees, and standing trees) and the need to reestablish position control on a separate control point once the angle from the RTS 'gun' became sub-optimal or a tree blocked too much of the 'gun' site.

Because of site access time constraints, it was decided with input and concurrence from the ESTCP Program Office to focus on 100 percent completion of a single grid. Grid 82/47 (**Figure 5-16**) had gaps identified by CH2M and the data were collected until only physical obstacles (not RTS 'gun' shadows) inhibited data collection. Because it took an additional 3 days to complete the gap fill on one grid (one-quarter of the planned survey area), by extrapolation it is estimated that an additional 9 days would have been required to fill all of the gaps in the planned survey areas.

Of the 0.89-acre footprint cleared, approximately 0.71 acre of dynamic detection data were collected with the TEMTADS. CH2M evaluated the dynamic TEMTADS data and selected 429 targets based on anomaly selection thresholds derived from IVS and dynamic test data.

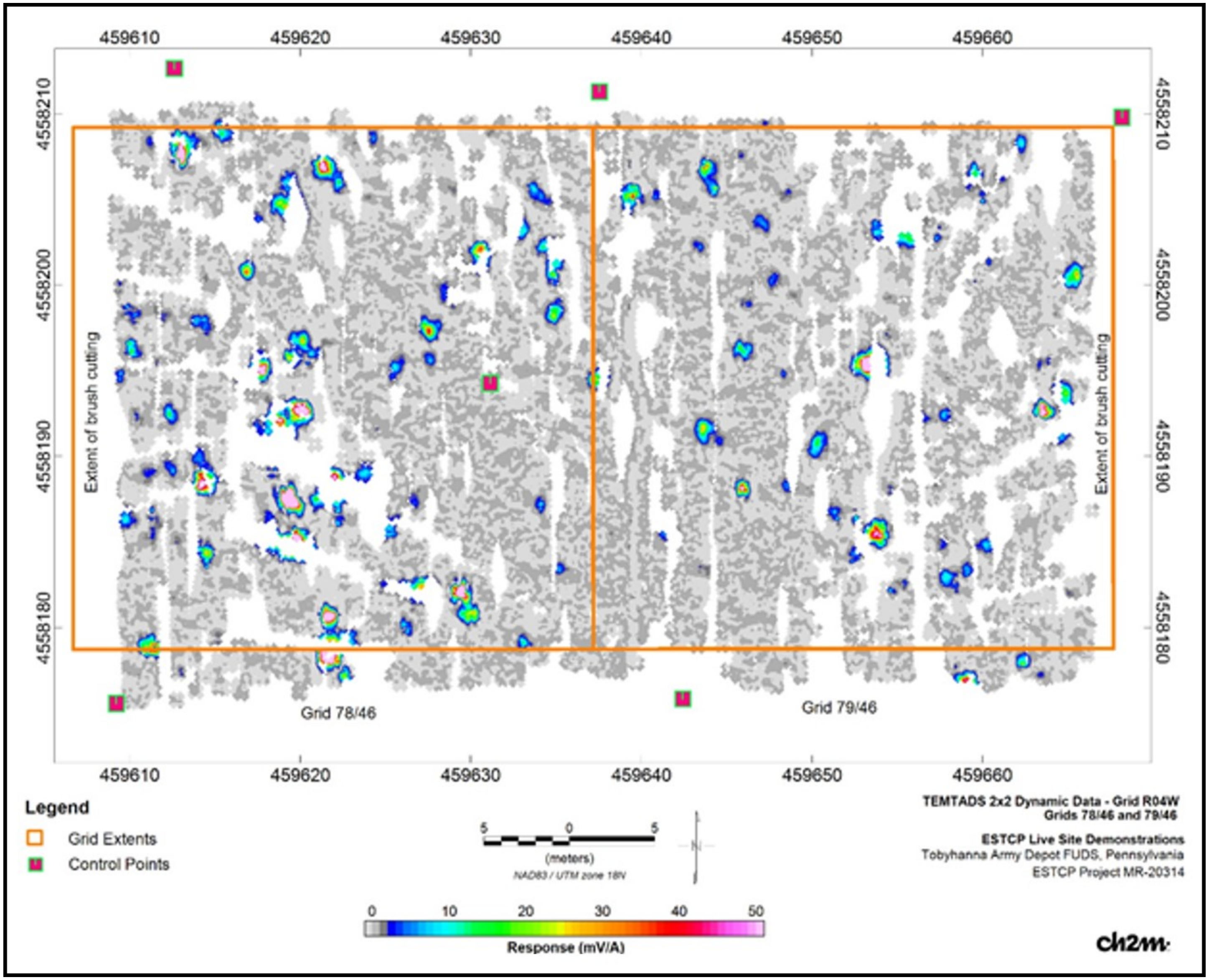


Figure 5-15. TOAR Dynamic TEMTADs 2×2 Survey in Grids 78/46 and 79/46 (Western)

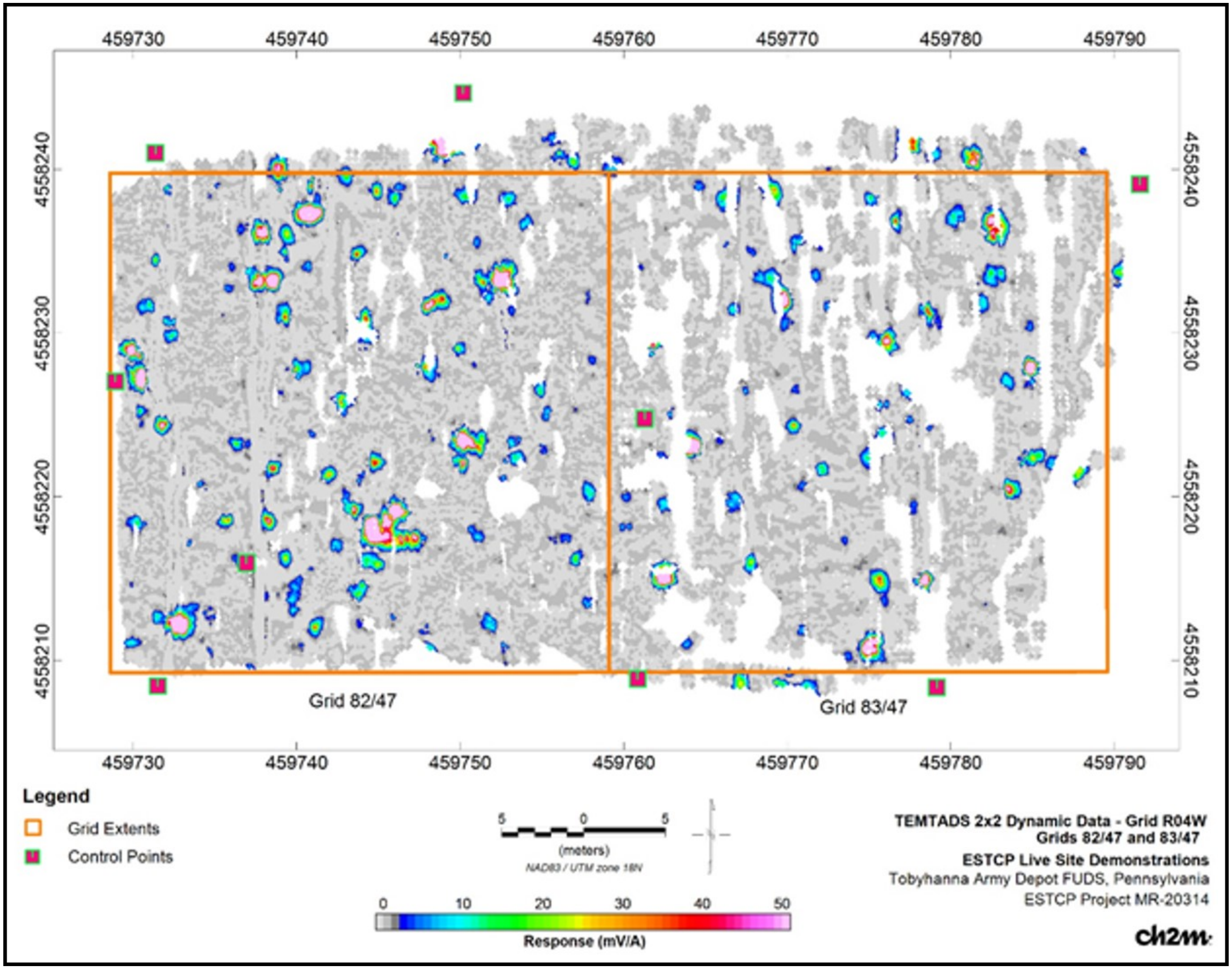
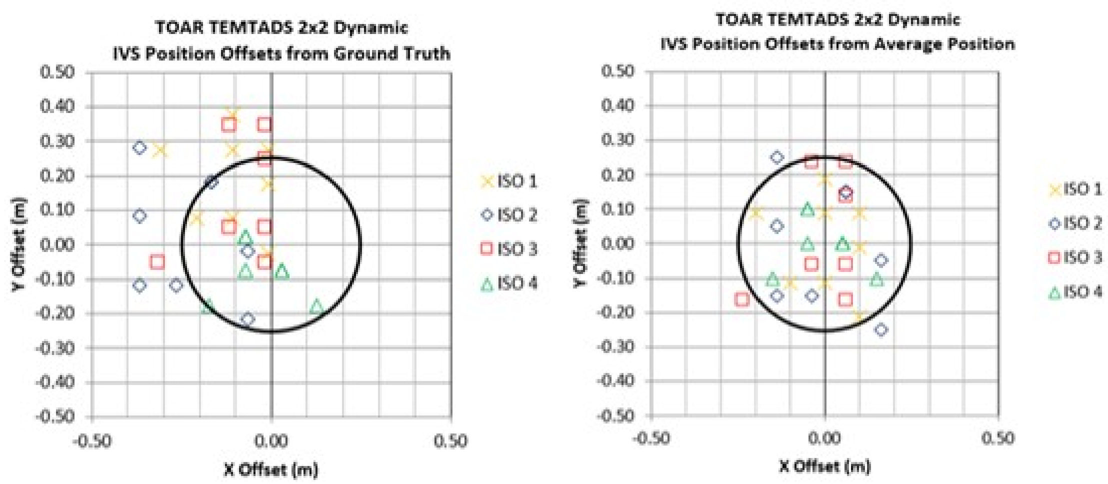


Figure 5-16. TOAR Dynamic TEMTADS 2×2 Survey in Grids 82/47 and 83/47 (Eastern)

5.8.2.2 Dynamic Data Quality Control

Throughout the course of the dynamic detection survey, the TEMTADS system was tested at the IVS on a twice-daily basis to verify proper system operation. In order to measure precision of the system, ongoing analysis was performed on the IVS detection results, with each successive day's results compared to the averaged results of all previous IVS surveys for detection offset and amplitude response of each seed item.

The positions were derived from the dynamic monostatic, *Z*-component response amplitude anomaly peaks using Geosoft's automatic peak picking algorithm. **Figure 5-17** (left) presents the position offsets (relative to the ground truth) for each of the IVS items. **Figure 5-17** (right) presents the position offsets from average position. The errors were outside the stated objective of 0.25 m (TOAR objectives presented in Section 7 of this document).



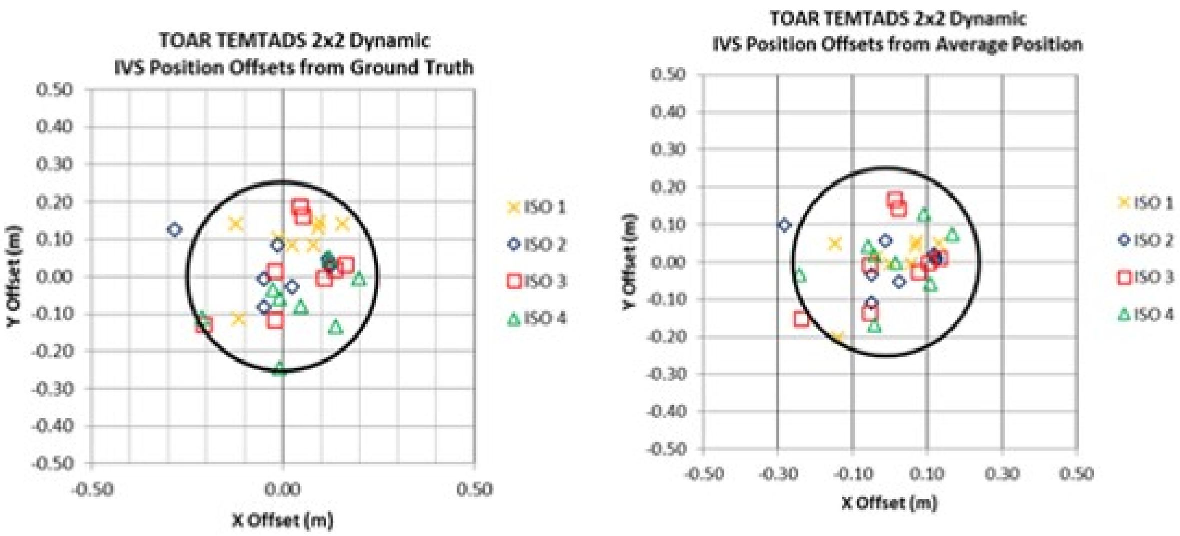
	Maximum Error (m)	Average Error (m)
ISO 1	0.39	0.24
ISO 2	0.46	0.29
ISO 3	0.37	0.20
ISO 4	0.25	0.12

	Maximum Error (m)	Average Error (m)
ISO 1	0.23	0.15
ISO 2	0.29	0.20
ISO 3	0.29	0.18
ISO 4	0.18	0.10

Figure 5-17. TOAR Dynamic TEMTADS 2×2 IVS Survey Position Results (Initial Processing)

During the field operations, the lack of positioning accuracy was assumed to be a function of the RTS operating in the wooded environment. After the project was completed, a review of the processing approach revealed that the data processor had failed to account for the extended height of the RTS prism above the TEMTADS array. Because of this, the pitch and roll positioning corrections were not accurate, and the accuracy of the results was compromised. The data were reprocessed using the correct positioning approach, and the results are provided in **Figure 5-18**. While these results indicate considerable improvement, there remains very little difference between the accuracy (results against ground truth) and the precision (variability in the results). This

indicates that the positioning methodology used does not have the same precision as a typical GPS-enabled approach. However, the precision in the results is comparable to that of a GPS-enabled EM61-MK2 survey, and the dig radius of 1 m used during the intrusive investigation was sufficient to mitigate the effects of these increased errors on locating the anomaly sources.



	Maximum Error (m)	Average Error (m)
ISO 1	0.21	0.15
ISO 2	0.31	0.12
ISO 3	0.24	0.15
ISO 4	0.25	0.15

	Maximum Error (m)	Average Error (m)
ISO 1	0.25	0.10
ISO 2	0.30	0.12
ISO 3	0.28	0.14
ISO 4	0.24	0.13

Figure 5-18. TOAR Dynamic TEMTADS 2×2 IVS Survey Position Results (Reprocessing)

In addition to the daily IVS measurements, the functionality of the TEMTADS sensor was assessed daily using a system 'function test' whereby the system response was challenged by placing a small ISO (schedule 80) on the top of the array housing. The function test results are presented on **Figure 5-19**.

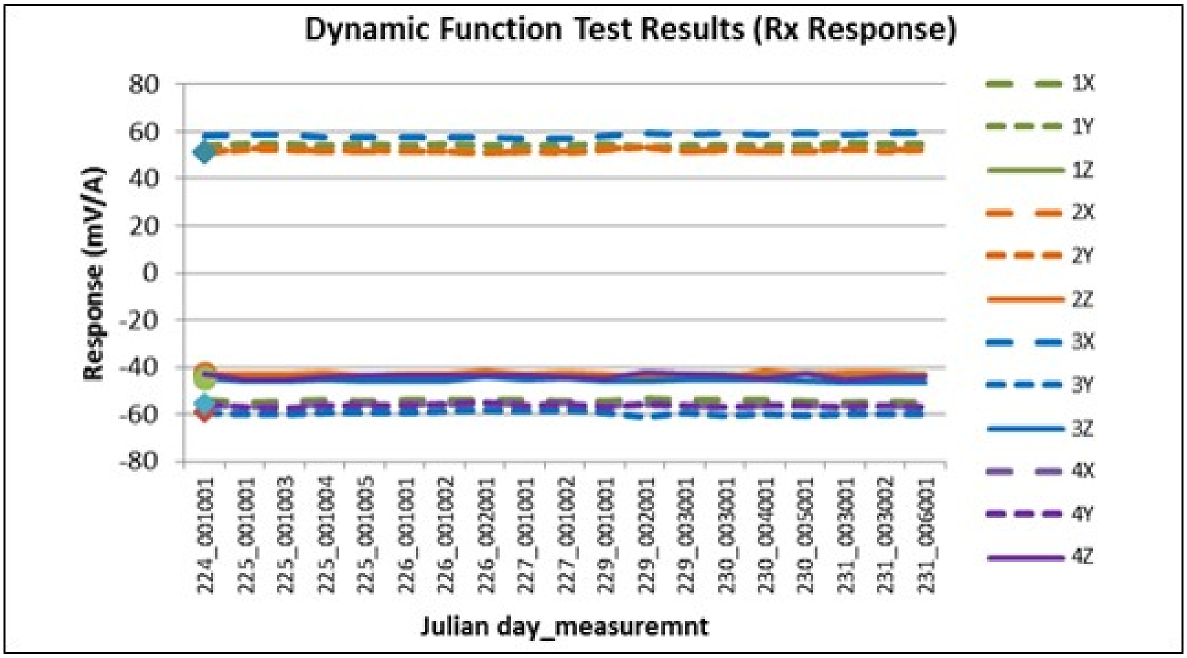


Figure 5-19. TOAR Dynamic TEMTADS IVS Survey Sensor Function Results

5.8.2.3 Dynamic Data Processing and Analysis

The raw data files, comprising raw sensor, RTS, and IMU data, were loaded into Geosoft's UXA software environment. The RTS and IMU data were merged with the sensor data to provide georeferenced positions for each TEMTADS Tx/Rx combination measurement. The monostatic *Z*-component Rx coil measurements were used as the basis for amplitude response anomaly detection.

The background monostatic *Z*-component responses were removed using a de-median filter in which long wavelength signals (because of spatially stable soil response and sensor 'zero level' drift) were modeled and removed by calculating the median over a large moving window and subtracting the median from the unleveled data. The final (leveled) data for each grid were interpolated to grid nodes evenly spaced at 5 cm using Geosoft's minimum curvature gridding routine. The interpolated Geosoft grid files were mosaicked to create a full-site Geosoft grid file from which anomalies were selected.

Targets were selected using amplitude response detection by applying Geosoft's peak detection function to the interpolated monostatic, *Z*-component responses at time gate 5 (0.137 ms). This is similar to conventional EM61-MK2 target detection, with the only difference being the higher resolution of the TEMTADS sensor because of the smaller Tx/Rx coil footprints and more densely sampled data set.

Detection performance is a function of the signal-to-noise ratio (SNR) of the detection method, where signal is derived as the peak anomaly response and the noise is calculated as the root mean square of the non-anomalous responses. Typically, a SNR of 5 is used to maximize detection of real targets while minimizing false detections because of noise in the data. The site-specific noise levels were estimated by calculating the standard deviation of the leveled data (assuming perfect leveling, root mean square noise is equivalent to the standard deviation of the signal) in non-anomalous regions. Noise levels of 0.46 mV/A resulted in a detection threshold of 2.3 mV/A.

This threshold provides a maximum reliable detection depth (assuming worst case orientation) of 30 cm for small ISOs (small ISOs are similar in response to 37-mm projectiles). Note that optimally oriented small ISOs and 37-mm projectiles will be detected at greater depths. Using this threshold, anomalies were automatically selected from the gridded data using Geosoft's peak detection algorithm. All anomaly selections were manually reviewed by the processing geophysicist, and manual additions or deletions were performed where required.

CH2M selected a total of 429 anomaly locations for cued interrogation. There were 165 selections in the western grids (**Figure 5-20**) and 264 selections in the eastern grids (**Figure 5-21**). In addition to these, 68 MPV targets selected by Black Tusk Geophysics were added to the cued interrogation and intrusive investigation lists. These targets were MPV targets located in the 100 percent coverage area (eastern grids) that did not have a corresponding TEMTADS anomaly location (due primarily to the fact the MPV could access locations that the TEMTADS could not).

5.8.2.4 Cued Data Collection

Cued surveys were performed with the TEMTADS over the course of 7 days, from 4 September (JD 247) to 17 September (JD 260), 2015. Data were recorded electronically as collected on the TEMTADS backpack data acquisition computer hard drive. The collected data were copied and backed up daily onto removable media and transferred daily to the data analyst for QC analysis.

All of the 429 targets detected by the TEMTADS were reacquired for cued interrogation with the TEMTADS. Cued measurements at the 68 MPV target locations that were not selected by the TEMTADS were also collected, resulting in a total of 497 reacquired targets.

5.8.2.5 Cued Data Quality Control

The QC implemented throughout the cued data collection included the following:

- IVS measurements before and after each day of production measurements
- Function tests collected whenever background measurements were collected
- Transmit current and receiver decay monitoring
- Field inversion monitoring
- Re-collection where horizontal target location was offset by more than 40 cm

Throughout the course of the cued data collection, the TEMTADS system was tested at the IVS on a twice daily basis to verify sensor functionality. The daily IVS measurements were inverted, and the extrinsic parameters (source location) and intrinsic parameters (source polarizabilities [βs]) results were monitored and recorded.

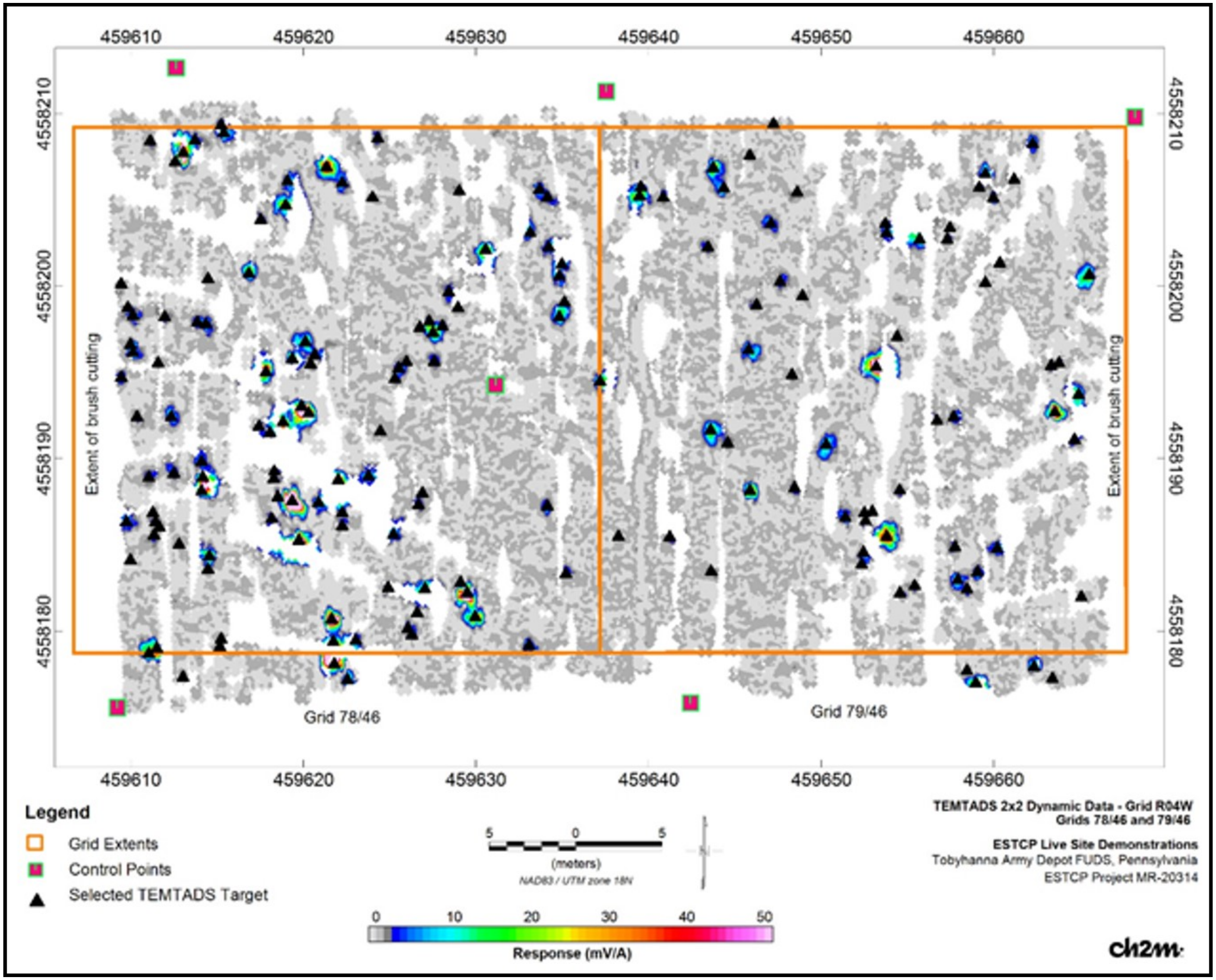


Figure 5-20. TOAR Dynamic Data with Cued Anomaly Selections in Grids 78/46 and 79/46 (Western)

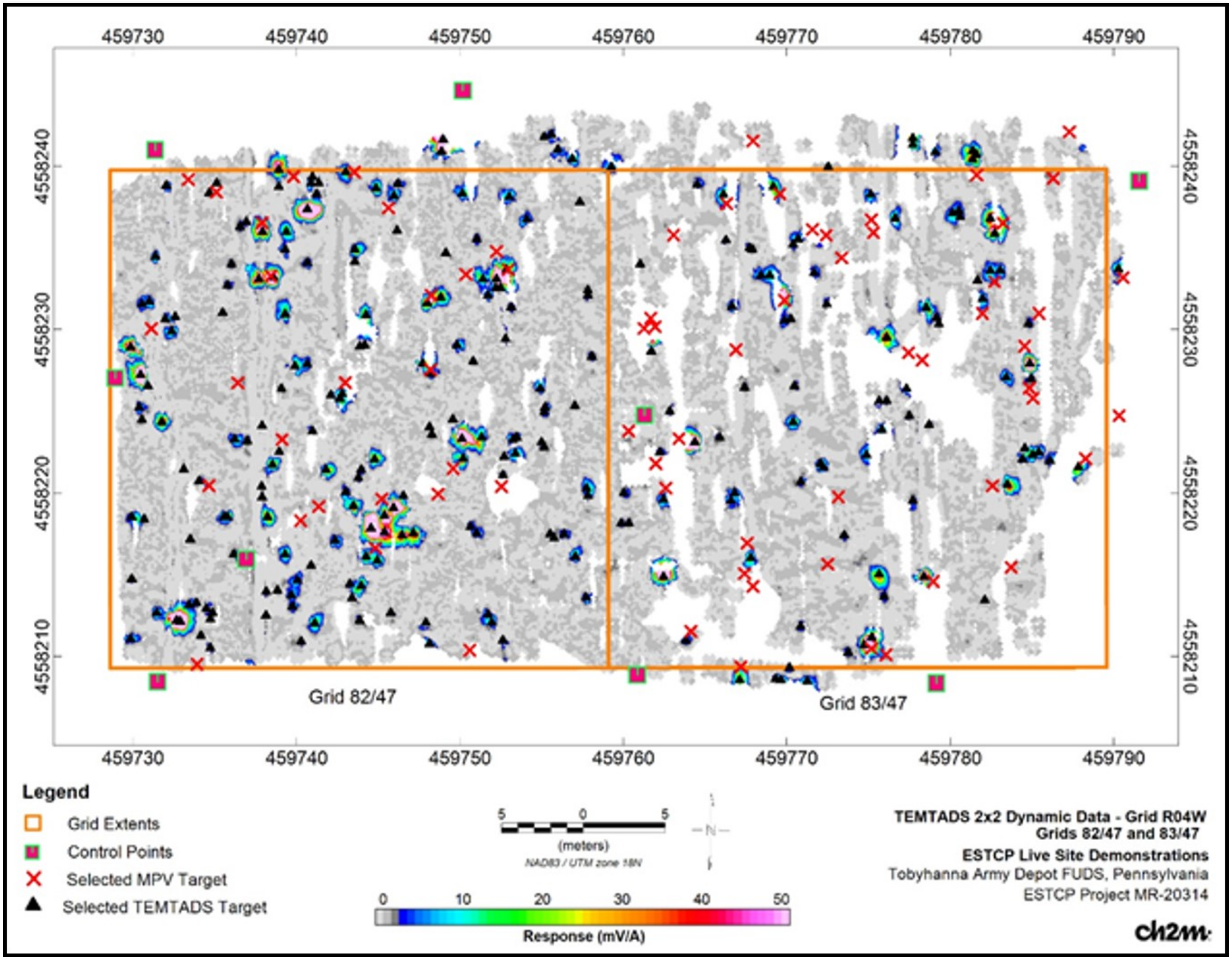


Figure 5-21. TOAR Dynamic Data with Cued Anomaly Selections in Grids 82/47 and 83/47 (Eastern Grids)

These results for the source locations are presented on **Figures 5-22**. All but one of the source position results obtained were within the measurement quality objective (MQO) of 25 cm for accuracy (position relative to the ground truth) and all of the results were within the 20 cm MQO for precision (offset from the average position). Because the accuracy results for ISO 1 exhibit a bias, and this bias is not present in the remaining ISOs, it is assumed that the MQO failure is attributable in part to inaccuracy in the ground truth for ISO-1.

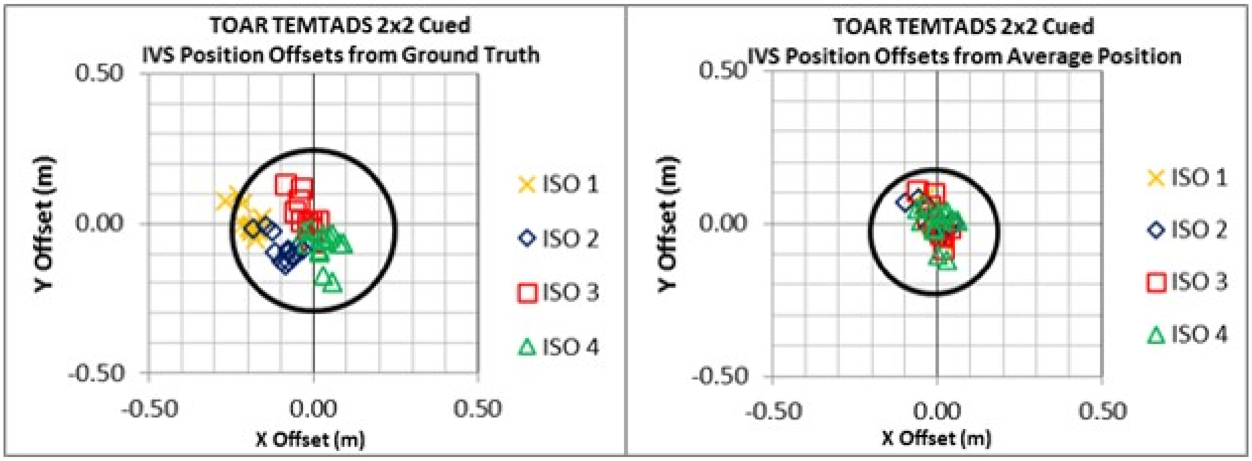


Figure 5-22. TOAR TEMTADS Cued Data IVS Dipole Fit Position Results: (Left) Offset from Ground Truth and (Right) Offset from Average Position

The derived source βs were assessed by performing a library match to derive decision metrics (described below in section 5.3.1) for each measurement and the results are presented on **Figure 5-23**. All measurements resulted in very good fits to their respective library entries, indicating proper operation of the system.

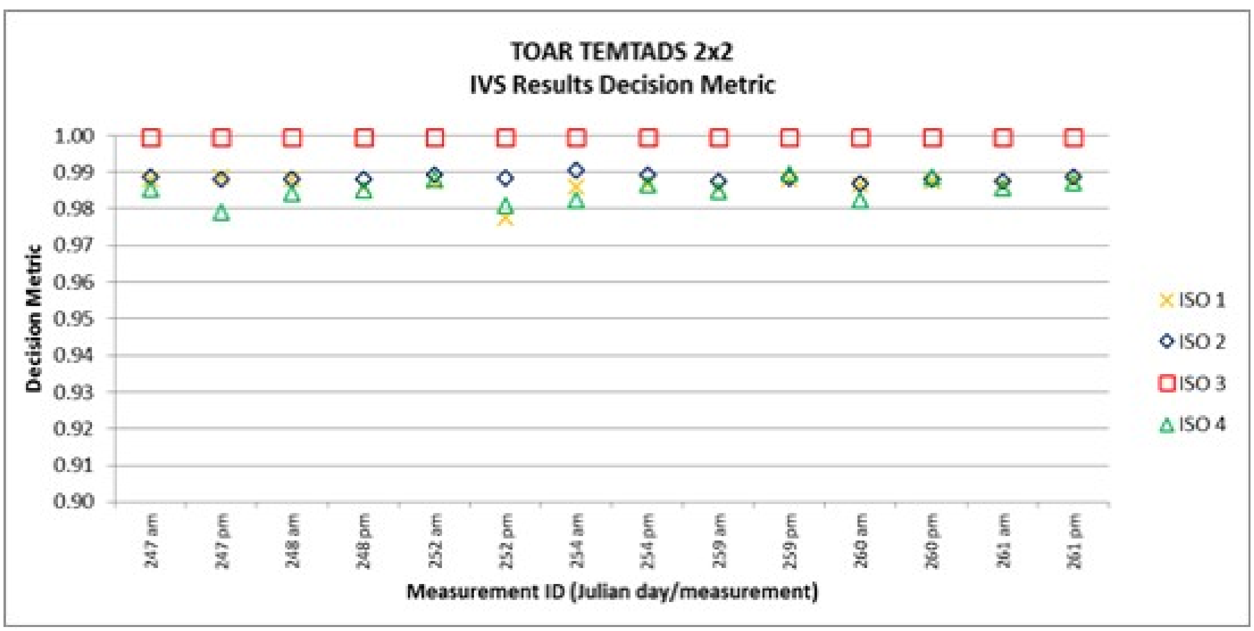


Figure 5-23. TOAR TEMTADS Cued IVS Decision Metric (Library Match) Results

In addition to the twice-daily IVS, in-field sensor functionality tests were performed throughout each survey day to confirm that the TEMTADS system components were functioning within project specifications. Sensor function tests were performed during each background data collection event. The sensor function test results are shown on **Figure 5-24**, **Figure 5-25,** and **Figure 5-26**.

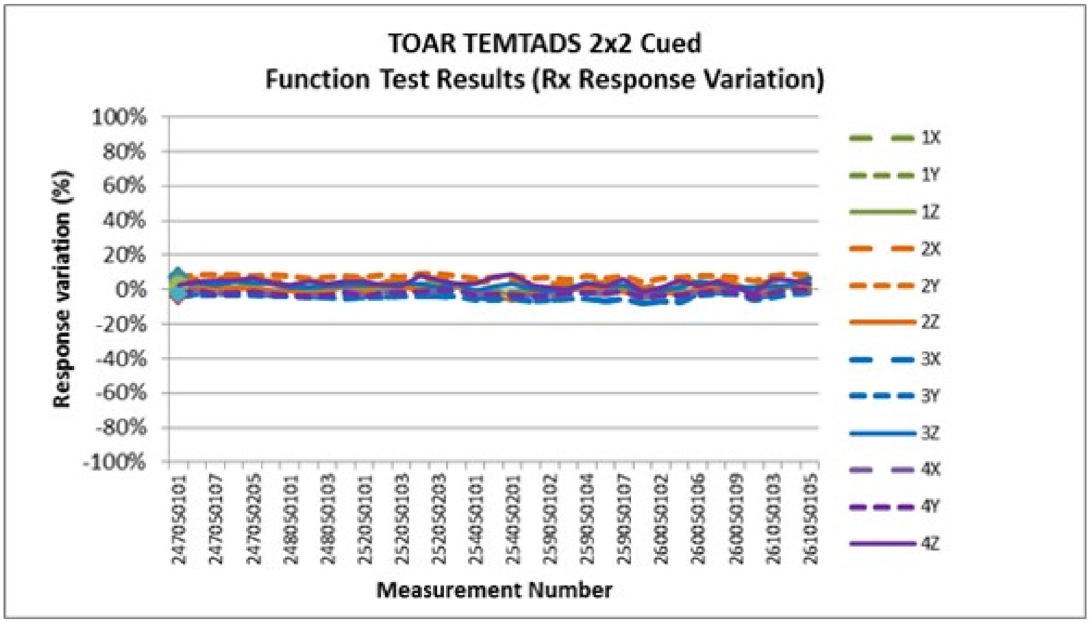


Figure 5-24. TOAR TEMTADS Cued Data Sensor Function Test Results Rx Response

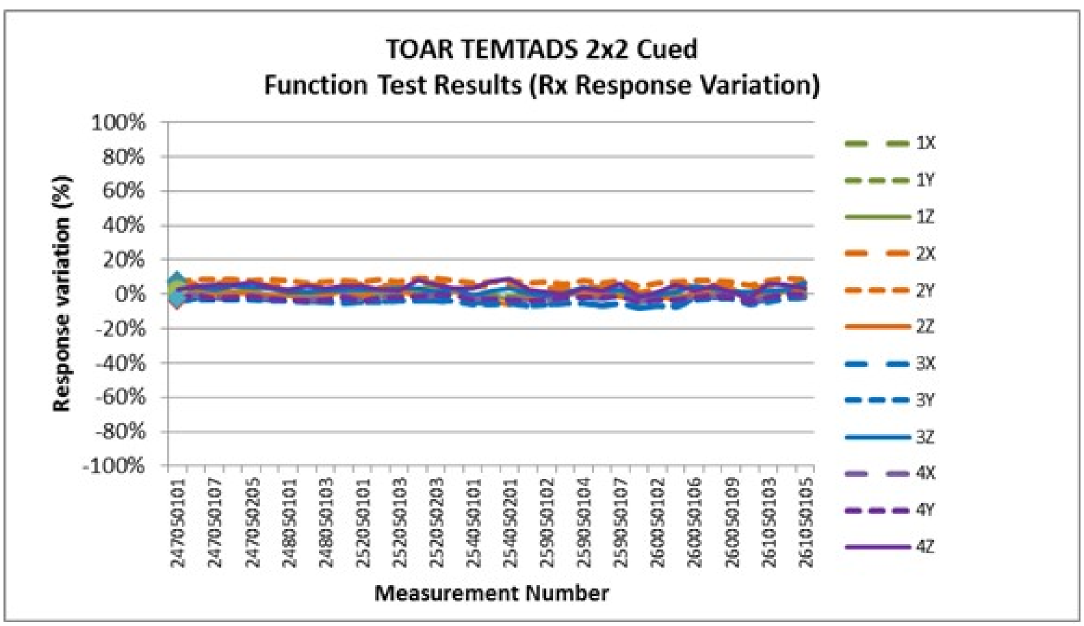


Figure 5-25. TOAR TEMTADS Cued Data Sensor Function Test Results Rx Response Variation

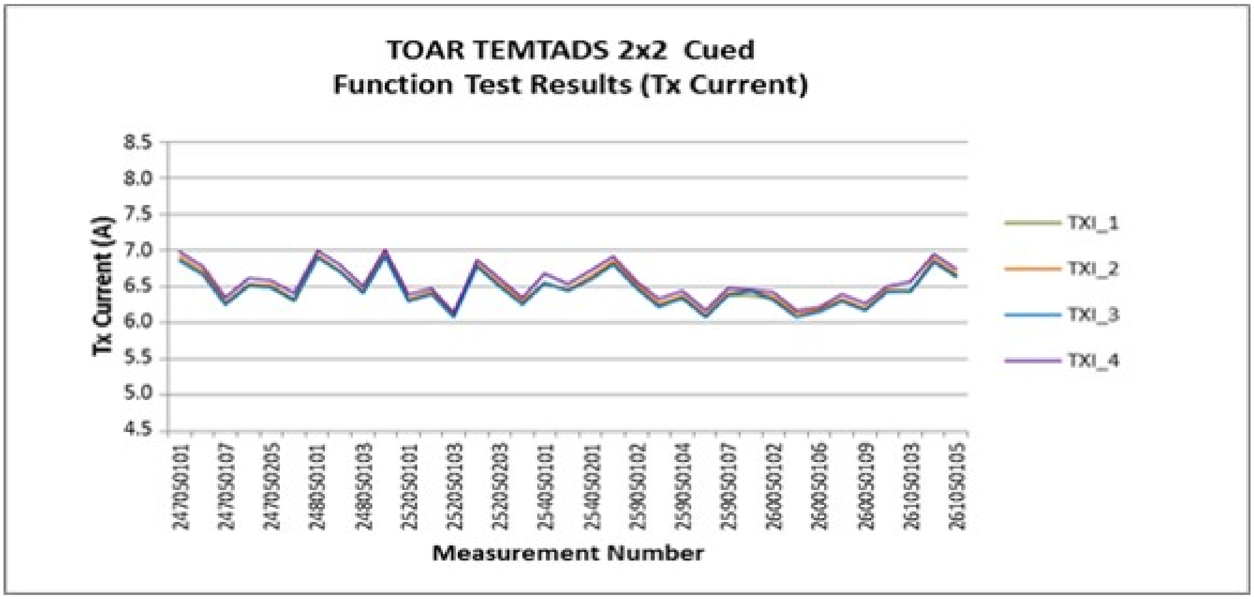


Figure 5-26. TOAR TEMTADS Cued Data Sensor Function Test Results Tx Current

5.8.2.6 Cued Data Processing and Post-acquistion Analysis

The data processing, analysis, and classification steps undertaken to generate a dig/no-dig decision for each target are described below. These steps were performed for the TEMTADS data using the UXA module within the Geosoft processing platform. The general processing flow is described in the following steps:

1. Target Association: cued measurements are associated with a particular target from the cued target list
2. Feature Selection: statistical analyses are performed to determine target features
3. Library Matching: target polarization curves extracted for each target are matched to a library of munitions known to exist in the area of interest
4. Analyst Calibration Digs: used to determine the source of any identified clusters of ‘like signatures’ as well as to inform the analyst with respect to the placement of decision thresholds in the prioritized list
5. Prioritized Target List Assembly: final AGC determinations on the set of cued targets and assembly of a final prioritized dig list

Cued data were imported into the Geosoft UXA module for data QC and inversion modeling. The data were levelled using background data collected at frequent time intervals over nearby, anomaly-free background locations. The measurements used for background correction were reviewed for variability and to identify any outliers which may correspond to measurements over subsurface metal. To minimize errors in the background removal process, spatial and temporal distance between the background and target measurements were minimized.

Target data were inverted using both single-source and multi-source dipole response models to estimate target parameters. The principle parameters of interest for use in classification of the targets were the three polarizabilities (β1, β2, and β3) estimated for each target by UXA. In addition to estimates for the three βs for each target, an estimated location and depth and fit coherence (i.e., the correlation between the observed responses and the model predictions) was also returned by UXA for each target during inversion.

Classification of each target was performed using the intrinsic features (βs) derived from the single-source and multi-source inversion processes. Classification was based primarily upon how well the derived βs matched the library of candidate TOI types. The final composition of the library was informed by a set of ACDs (described in detail in Section 5.6.2.8).

5.8.2.7 Library Match Decision Metric

Classification is based primarily on the goodness-of-fit metric (values from 0.0 to 1.0) generated by UXA during a comparison of the β values estimated for each surveyed target and the β values in the site-specific library of candidate munitions. This comparison is performed via the library match utility in UXA. The goodness-of-fit metric is a measure of the fit correlation between a target and the library entry that best fits that target, with higher values indicating a better fit between the target and the corresponding item in the library. The library fit analysis matches the following four combinations of βs to those of the candidate library TOIs:

- β1, β1/β2, β1/β3
- β1, β1/β2
- β1/β2, β1/β3
- β1

The confidence metrics for each fit combination are averaged to derive a 'decision metric'. This library matching process is performed for each single-solver model and every target in each of the multi-source solver candidate realization models. For each flag position, the best library fit from the single-solver and multi-solver targets is used as the decision metric, which is subsequently used to rank and classify the target list. Values below the analyst threshold (nominally 0.825) are considered non-TOI. The analyst threshold was refined using results from a set of ACDs.

5.8.2.8 Analyst Calibration Digs

Because all identified anomalies were intrusively investigated, ACDs were not performed separately from the intrusive investigation phase. Instead, the ACDs were simulated through requests for ground truth from the ESTCP Program Office. The following sections describe the rationale for the ACD selections.

CLUSTER ANALYSIS

A 'cluster analysis' designed to identify signatures that are ubiquitous to the site was performed using the UXA signature matching/cluster identification routines. For identified clusters that were not already represented in the library, representative samples were selected for addition to the set of ACDs (in this case, 'selections' provided on request by the ESTCP Program Office to simulate the ACD process) to confirm that they are not because of an unexpected TOI.

FEATURE SPACE ANALYSIS

In addition to the library match decision metric described above, a feature space analysis was also performed to identify any targets that did not match a specific library entry but had the combined characteristics of being large, rotationally symmetric, and thick-walled. Targets identified with these characteristics were selected and added to the ACD selection list.

DIG/NO-DIG THRESHOLD CALIBRATION

The ACDs were also used to finalize the analyst threshold (i.e., the decision metric cutoff value separating the prioritized list into dig/no-dig classifications). These targets were selected by sampling each library match munition type above and below the initial starting metric of 0.825. Because the analyst threshold must be set low enough to identify TOIs that have noisy polarizabilities as TOIs, where possible targets that looked qualitatively like a TOI were preferentially selected. Although final classification is based upon objective numeric criteria, qualitative selection of these threshold calibration digs is required to preferentially select those targets that are likely to be TOIs, thus calibrate the threshold appropriately.

LIBRARY ENTRY VERIFICATION

The initial library contained a comprehensive list of munitions including entries that were not in the list of munitions expected to be onsite but were conservatively left in as a representative size/shape sample. Where one or more of these entries resulted in a significant number of matches, they were sampled to determine if they were actual TOIs. Where these samples did not result in the recovery of a TOI, these entries were removed from the final site-specific list. Selection of targets with noise-free polarizabilities does not inform the threshold calibration because if they are near the threshold they will not be TOIs.

5.8.2.9 Candidate TOI Library

The initial candidate library consisted of a comprehensive range of munitions that are delivered with the UXA installation files (listed on the left side of **Figure 5-27**). The final site-specific library of candidate TOIs comprised munitions expected to be onsite, as confirmed by the results of the ACDs. The site-specific library had one or more entries for each item listed on the right-hand side of **Figure 5-27**.

Comprehensive Library (all UXO)			
Type	Size	Decay	Symmetry
Small ISO	0.21	0.031	1.02
rifle grenade	0.79	0.009	1.03
medium ISO	0.98	0.046	1.06
large ISO	1.54	0.054	1.02
81mm	1.36	0.032	1.05
75mm	1.08	0.057	1.01
60mm	0.79	0.038	1.01
5in proj	1.70	0.058	1.05
57mm	0.68	0.056	1.02
40mm grenade	0.28	0.092	1.01
3in stokes mortar	1.38	0.070	1.15
3in proj	1.14	0.052	1.02
37mm	-0.08	0.092	1
2.36in rocket	1.17	0.075	1.19
155mm_proj	2.10	0.050	1.13
105mm proj	1.59	0.059	1.14
20mm	-0.30	0.022	0.98
MK2 Hand grenade	0.32	0.001	1.04
Fuze Piece/part/component	-0.45	0.009	1.1

TOAR Library Entries			
Munition	Size	Decay	Symmetry
Small ISO	0.21	0.030	1.02
Medium ISO	0.98	0.050	1.06
Large ISO	1.54	0.050	1.02
37-mm projectile	0.20	0.060	1.00
75-mm projectile	1.08	0.057	1.01
155-mm projectile	2.10	0.050	1.13

Figure 5-27. Initial (left) and Final, Site-specific TOI Library (Right) for TOAR

5.8.2.10 Intrusive Activity, Procedures, and Results

CH2M performed intrusive operations from 13 September through 1 October 2015. All prosecuted targets were investigated and documented according to the procedures outlined below.

- **Reacquisition of targets**. Targets were previously reacquired by the PLS for the cued interrogation using RTS. The pin flag was located approximately 50 cm north of the paint mark denoting the target location.
- **Intrusively investigate the anomaly**. Anomalies were excavated to 30 cm below the expected depth below ground surface, within a 50 cm radius from the marked-out anomaly location.
- **Identify recovered item**. All items recovered were inspected by the UXO Safety Officer and Senior UXO Supervisor to ensure that each item was properly identified and documented.
- **MRSIMS data entry/whiteboard and photo.** Field observations of each recovered item were entered into CH2M's MRSIMS field tablets. The exact location and depth of each item was recorded by a CH2M field geophysicist using the RTS. Required information was written onto a whiteboard, and a photo was taken with the item.
- **Post-dig clearance**. Before declaring a dig complete, each area was swept with a Schonstedt magnetometer and a White's All Metal detector to determine if any additional items remained.
- **QC check**. Approximately 10 percent of all excavations were checked by UXO QC personnel with the Schonstedt magnetometer and a White's All Metal detector to ensure the hole was clear.

- **Backfill hole**. Once the excavation was declared clear, the hole was backfilled to grade.

All of the TEMTADS cued targets were intrusively investigated as well as a set of MPV targets located in the 100 percent coverage area. Time constraints imposed by site access limitations did not allow for all of the MPV targets outside the 100 percent coverage area to be investigated. During the intrusive investigation, all of the QC seeds were located within the 40 cm MQO and recovered. The results of the intrusive investigations were provided to the ESTCP Program Office and are not presented in this report.

5.8.2.11 Deliverables

The following deliverables resulted from the data collection at TOAR:

1. **Dynamic detection data:** Raw and processed dynamic detection data were provided to the ESTCP Program Office, along with a final target list based on the established detection threshold
2. **Cued data:** Raw sensor data (*.tem) and associated GPS/IMU data (*.gps)
3. **Cross-reference list**: A text readable table that associates TEMTADS filenames with each Target ID, and provides any applicable collection notes
4. **Intrusive results:** The intrusive results were provided to the ESTCP Program Office in the form of a table listing the results for each location identified for intrusive investigation as well as photos detailing the metallic items that were removed from each location. Note that all of the intrusive results were firewalled from the data analyst until after the analysis was completed (with the exception of the ACD selections described above).

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6.0 PERFORMANCE ASSESSMENT NBAFS

The performance objectives for this classification survey and the corresponding results are summarized in **Table 6-1**. Details on the results for each objective are subsequently discussed in the following sections.

Table 6-1. NBAFS Performance Objectives and Results

Performance Objective	Metric	Data Required	Minimum Acceptable Criteria	Nominal Success Criteria	Result
Data Collection Performance Objectives					
Dynamic survey spatial coverage	Effective footprint coverage	Mapped survey data	95% coverage at line spacing of 60 cm with no gaps greater than 20 cm (80 cm between adjacent line centers)	100% coverage at 60 cm line spacing	Pass – 100% of area surveyed at ≤ 60 cm lane spacing
Along line measurement spacing	Point to point sample distance	Mapped survey data	95% ≤ 20 cm	98% ≤ 15 cm	Pass - >95% of mapped survey data < 20 cm point to point sample distance
Detection of all TOI	Percent of seed items detected	Seed item locations Geo-referenced anomaly list	100% of seeded items within a 50-cm halo	100% of seeded items within a 25-cm halo	Pass – 100% of seeded items detected within a 50-cm halo
Data positioning repeatability	Precision of dipole-fit derived extrinsic target features	Target fit positions from daily instrument verification strip (IVS)	Dynamic positions ± 20 cm	Dynamic positions ±10 cm	Pass
Sensor response repeatability (dynamic and cued surveys)	Precision of dipole fit derived intrinsic target features	Dipole-fit derived βs from daily IVS data	≤ 20% RMS variation in β amplitudes	≤ 10% RMS variation in β amplitudes	Dynamic: Pass – Amplitude RMS variation was <20% Cued: Pass –β Amplitude RMS variation was <20%
Cued interrogation anomaly coverage	Instrument position	Cued data	95% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	Pass

Table 6-1. NBAFS Performance Objectives and Results (Continued)

Performance Objective	Metric	Data Required	Minimum Acceptable Criteria	Nominal Success Criteria	Result
Data Analysis/Classification Performance Objectives					
Maximize correct classification of TOI	Number of TOI correctly identified	Ranked anomaly lists Scoring reports from Institute for Defense Analysis	98% of all seeded targets 95% of all TOI	100% of all seeded targets 100% of all TOI	Fail – see discussion in Section 5.2
Maximize correct classification of non-TOI	Number of false alarms eliminated	Ranked anomaly lists Scoring reports from Institute for Defense Analysis	Reduction of clutter digs required by >50% while retaining all TOI	Reduction of clutter digs required by >75% while retaining all TOI	In retrospect this was not achievable: 70% of all digs resulted in TOI.
Model results support classification decision	Number of anomalies classified as 'Cannot Analyze'	Modeling fit coherence results	90% of targets have fit coherence > 0.80	95% of targets have fit coherence > 0.80	N/A – classification was not performed
Correct estimation of target parameters	Accuracy of estimated target locations for seed items	Modeled target parameters Results of intrusive investigation	X,Y < 15 cm (1σ) Z < 10 cm (1σ)	X,Y < 15 cm (1σ) Z < 10 cm (1σ)	Fail – see discussion

σ = sigma (standard deviation)

6.1 DYNAMIC SURVEY SPATIAL COVERAGE

The TEMTADS dynamic detection survey was designed to provide 100 percent coverage of the investigation area. A planned transect spacing of 60 cm was used to ensure sufficient overlap of the 80 cm sensor swath footprint between traverses. Before the dynamic detection survey in each grid, 1 m wide survey lanes were established using ropes held in place by non-metallic tent stakes. This ensured consistent spacing between transects and even coverage of the investigation area.

The success criteria for this objective was 95 percent coverage of the investigation area with no gaps greater than 80 cm between adjacent lines. This objective was achieved, as no gaps greater than 80 cm were observed in the data, and complete coverage of the investigation area was achieved.

6.2 ALONG-LINE MEASUREMENT SPACING

The TEMTADS dynamic detection survey was designed to have an along-line measurement spacing of 15 cm or less so as to provide a dense detection dataset. The success criteria for this objective was for 98 percent of mapped data points to be within 15 cm of the along-line neighboring data point, and for no more than 5 percent of the data points to be outside of 20 cm from the along-line neighboring data point. This objective was achieved, as no along-line spacing greater than 15 cm was observed in the data.

6.3 DETECTION OF ALL TOI

This objective involved the detection of TOI during the dynamic detection survey. This objective was verified using a blind seeding program. Before the dynamic detection survey, 110 seed items were buried within the investigation area. These seed items consisted of Small ISO Schedule 80s, 0.5-inch x 2-inch 20-mm simulants, 0.5-inch x 3-inch 20-mm simulants, and inert 20-mm projectiles. The 20-mm and 20-mm simulants were buried at depths up to 15 cm, and Small ISO (Schedule 80) were buried at depths up to 30 cm, as documented in the Demonstration Seed Plan.

6.4 DATA POSITIONING REPEATABILITY

This objective involved twice daily surveys of the seeded items in the IVS to show that the data positioning was repeatable to better than 0.2 m. The positions of the seeded items in the dynamic survey were determined as the locations of the amplitude response anomaly peaks associated with the seeded items. All detections were within the specified 0.2 m tolerance. The results are summarized in **Table 6-2**.

Table 6-2. NBAFS Dynamic IVS Positioning Results

Seed Item	Maximum Error (m)	Average Error (m)
M55A3B1 20-mm	0.15	0.06
2.25-inch Rocket	0.17	0.04
Small ISO80	0.17	0.07

The positions of the seeded items surveyed during the cued investigation were derived from the dipole fit analysis of the measured data. These results are summarized in **Table 6-3**. One of the results exceeded the stated tolerance, but the cause for the exceedance was a base station battery failure that occurred just before the very last measurement of the day (and after the other two IVS items had been successfully surveyed at the end of the day). Thus the failure was deemed to have no adverse implications for the usability of the day’s data.

Table 6-3. NBAFS Static IVS Positioning Results

Seed Item	Maximum Error (m)	Average Error (m)
M55A3B1 20-mm	0.10	0.05
2.25-inch Rocket	0.13	0.08
Small ISO80	0.36	0.10

6.5 SENSOR RESPONSE REPEATABILITY

This objective involves the repeatability of sensor response amplitude over the course of the project for each seed item buried at the IVS. Consistent sensor responses can only be obtained if the sensor is functioning properly. Sensor response amplitudes for each IVS data collection event were tracked throughout the life of the project for both the dynamic and cued phases of data collection. The objective was considered to be met if there was less than 20 percent RMS deviation in response amplitudes for dynamic and cued IVS results.

Results for the dynamic data responses are detailed in **Table 6-4**. The largest RMS deviation was for the 20-mm, at 9.9 percent, which means that this objective was achieved for the dynamic data phase of the demonstration.

Table 6-4. NBAFS Dynamic Data Sensor Response Results

Seed Item	Average Response (mV/A)	% RMS Deviation
M55A3B1 20-mm	9.6	9.9
2.25-inch Rocket	147.2	4.6
Small ISO80	28.4	6.5

Results for the cued β amplitudes are detailed in **Table 6-5**. The β amplitudes for the IVS seed items were within the 20 percent RMS tolerance established for this performance objective.

Table 6-5. NBAFS Cued Data Sensor Response Results

Seed Item	Average β Amplitude	% RMS Deviation
M55A3B1 20-mm	0.2	4.8
2.25-inch Rocket	44.3	4.6
Small ISO80	1.7	3.3

6.6 CUED INTERROGATION OF ANOMALIES

This objective requires that 95 percent of anomalies result in having the target fit location within a 0.4 m horizontal radius from the center of the array. This is required to ensure that the target is properly energized along its three principal axes. This metric was not achieved at NBAFS – only 75 percent of anomalies resulted in target fit locations within the stated radius. This was because of the fact that the majority of the measurements were made at locations with multiple targets in view. The field team used a single target inversion routine to reposition the sensor if the target was not within the specified radius. In a multi-target scenario, the real-time feedback is imprecise and there is no way to ensure that the most likely TOI will be within the 0.4 m radius of the sensor.

6.7 MAXIMIZE CORRECT CLASSIFICATION OF TOI

Not applicable (see classification discussion above).

6.8 MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

Not applicable (see classification discussion above).

6.9 MODEL RESULTS SUPPORT CLASSIFICATION

This objective requires that the model derived during the inversion process must match the observed data to within a correlation of 0.8. This metric, provided by UXA as the 'fit coherence' (UXA_fit_coh), is an output of the dipole analysis inversion routine. 98 percent of the inversion results resulted in fit coherence greater than 0.8.

6.10 MODEL RESULTS SUPPORT CLASSIFICATION

This objective involved assessing the accuracy of the derived target parameters by comparing the seed ground truth with the positions derived from the inversion process. There were very few seeds that were investigated (because of the fact that the seeds were originally distributed over the entire site and only a small section of the site was subject to cued investigation). Given the failure of the derived signatures to accurately predict the anomaly sources when more than three sources were recovered, and the fact that 33 percent of the flags had four or more sources recovered, it was determined that any analysis of performance against the few emplaced seeds that were measured would add no value to the demonstration.

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7.0 PERFORMANCE ASSESSMENT TOAR

The performance objectives for this classification survey and the corresponding results are summarized in **Table 7-1**. Details on the results for each objective are subsequently discussed in the following sections.

Table 7-1. TOAR Performance Objectives and Results for this Demonstration

Performance Objective	Metric	Data Required	Minimum Acceptable Criterion	Result
Dynamic survey spatial coverage	Effective footprint coverage	Mapped survey data	100% at ≤ 75 cm cross-track measurement spacing with intended spacing of 50 cm	Fail (pass for 100% coverage area)
Along-line measurement spacing	Point to point sample distance	Mapped survey data	98% ≤ 25 cm; no gaps > 40 cm unless obstruction or hazard is present	Fail (pass for 100% coverage area)
Detection of all TOIs	Percent of seed items detected	Seed item locations Georeferenced anomaly list	100% of seed items within a 40 cm radius of ground truth	Fail (all seed items were detected but two were not within the specified distance because of gaps in coverage)
Initial dynamic survey data positioning	Accuracy of derived target positions	Derived target positions from initial measurements at the IVS	Derived positions within 25 cm of the ground truth	Fail (one outlier from horizontal targets–at 31 cm)
Ongoing dynamic survey data positioning	Precision of derived target positions	Derived target positions from daily measurements at the IVS	Derived positions within 25 cm of the average positions during ongoing daily measurements	Fail (two outliers from horizontal targets—all within 30 cm)
Initial cued survey data positioning	Accuracy of dipole-fit-derived target positions	Target fit positions from initial measurements at the IVS	IVS item fit locations within 25 cm of ground truth locations	Pass
Ongoing cued survey data positioning	Precision of dipole-fit-derived target positions	Target fit positions from daily measurements at the IVS	IVS item fit locations within ±20 cm of average fit locations during ongoing daily measurements	Pass
Initial cued sensor polarizability accuracy	Accuracy of dipole-fit-derived intrinsic target features	Dipole-fit-derived polarizabilities from initial measurements at the IVS	Library match metric ≥0.9 to initial polarizabilities for each set of inverted polarizabilities	Pass
Ongoing cued sensor polarizability precision	Precision of dipole-fit- derived intrinsic target features	Dipole-fit-derived polarizabilities from daily measurements at the IVS	Match metric ≥0.95 to initial polarizabilities at the IVS for each set of inverted polarizabilities from daily measurements	Pass
Cued interrogation anomaly coverage	Instrument position	Cued data	100% of anomalies where the center of the array is positioned within 30 cm of anomaly location	Pass
Correct classification of TOIs	Number of TOIs correctly identified	Ranked anomaly lists Scoring reports from ESTCP Program Office	100% of all seed targets 100% of all TOIs categorized as 'dig' or 'cannot analyze'	Pass
Model results support classification decision	Number of anomalies classified as 'cannot analyze'	Modeling fit coherence results	≥90% of targets have fit coherence > 0.80	Pass

7.1 DYNAMIC SURVEY SPATIAL COVERAGE

The TEMTADS dynamic detection survey was designed to provide 100 percent coverage of the investigation area. A planned transect spacing of 50 cm was used to ensure sufficient overlap of the 80 cm sensor swath footprint between traverses. Data were collected continuously with an even walking pace; this consistent pace allowed the RTS base to reestablish contact with the RTS prism on the TEMTADS after it emerged from behind an obstacle. Using this approach, two types of gaps exist in this data set: one caused by the RTS 'gun' shadow created when the TEMTADS is carried behind a tree, and one created by obstacles such as downed trees, upright trees, and boulders. For the case of the RTS shadow, data were not interpolated even though the dynamic TEMTADS data were still being collected and there were positioning data on either side of the tree, the positioning data were not interpolated in processing. As in any survey, obstacles such as trees and boulders precluded coverage. To achieve the stated goal of 100 percent coverage, gaps because of interruption of the RTS data required re-collection, whereas gaps because of physical obstructions were documented as such.

As a result of time constraints, the gap fill required to achieve the 100 percent coverage goal was performed on only one of the four grids (grid 82/47). Coverage for this grid was 81.2 percent before gap fill and 94.1 percent post gap fill because of the elimination of gaps associated with the RTS. The 5.9 percent of the grid not mapped was the result of physical obstructions; thus the 100 percent coverage metric was achieved for this grid. Grids 78/46 and 79/46 (western grids) combined had an overall coverage of 72.4 percent with no gap re-collection. The gap percentage because of obstacles was not calculated because the locations of these objects were not recorded. Grids 82/47 and 83/47 (eastern grids) combined had 71.2 percent coverage, not accounting for obstacles.

7.2 ALONG-LINE MEASUREMENT SPACING

The TEMTADS dynamic detection survey was designed to have an along-line measurement spacing of 15 cm or less so as to provide a dense detection dataset. The success criterion for this objective was for 98 percent of mapped data points to be within 25 cm of the along-line neighboring data point. This objective was not achieved as gaps in coverage created by the RTS 'gun' shadow were not interpolated. The heavily wooded site inhibited the continuous contact between the base RTS and the prism located on the TEMTADS.

7.3 DETECTION OF ALL TOI

This objective involved the detection of TOIs during the dynamic detection survey using the blind seeding program. Before the dynamic detection survey 20 seed items were buried within the investigation area. These seed items consisted of small schedule 80 ISOs and medium schedule 40 ISOs buried at depths up to 17 cm. The minimum acceptable criterion of 100 percent of seed item locations being predicted within a 40 cm radius of ground truth was not met (**Table 7-2**). With the exception of Seed 1 and Seed 4, all other seed items were detected within the 40 cm radius from the recorded PLS position. The detection distance for Seeds 1 and 4 was outside of the MQO because of the gaps in coverage discussed in Section 7.1. All of the seeds in the 100 percent detection grid passed the 40 cm MQO.

Table 7-2. TOAR TEMTADS QC Seed Detection

Seed ID	Delta X (m)	Delta Y (m)	Distance (m)
1	-0.56	0.00	0.56 [a]
2	0.03	0.21	0.22
3	-0.13	-0.20	0.24
4	-0.17	-0.39	0.43 [a]
5	0.34	-0.10	0.35
6	0.08	0.03	0.09
7	-0.11	0.05	0.13
8	0.12	-0.16	0.20
9	0.13	-0.06	0.14
10	-0.31	-0.06	0.32
11	0.10	-0.28	0.30
12	0.16	0.28	0.32
13	0.18	-0.01	0.18
14	-0.05	-0.06	0.08
15	0.07	-0.13	0.14
16	-0.24	-0.02	0.24
17	0.13	-0.11	0.17
18	0.08	0.16	0.18
19	0.08	-0.06	0.10
20	0.29	0.12	0.32

[a] Outside the MQO.

7.4 INITIAL DYNAMIC IVS SURVEY DATA POSITIONING

This objective was to demonstrate positioning accuracy during initial dynamic data collection over the IVS with the TEMTADS by deriving positions within 25 cm of ground truth. The metric was assessed by evaluating the derived target positions from the initial data collection at the IVS as determined by the amplitude response anomaly peaks associated with the seeded items. Results for the dynamic data responses are provided in **Table 7-3**. The largest deviation was 39 cm for ISO-1, which means that this objective was not achieved for all ISOs.

Table 7-3. TOAR TEMTADS Initial Dynamic IVS Survey Positioning Results

Seed Item	Error (m)
ISO-1	0.39
ISO-2	0.25
ISO-3	0.25
ISO-4	0.08

7.5 ONGOING DYNAMIC SURVEY DATA POSITIONING

This objective involved the repeatability of sensor response amplitude over the course of the project for each seed item buried at the IVS. The minimum success criterion was that the derived positions of the IVS targets would be within 25 cm of the average positions derived from the ongoing daily IVS measurements. This approach gives an estimate of the precision of the positioning and is independent of any ground truth errors. Results for the dynamic data responses are detailed in **Table 7-4**. The largest deviation was 30 cm for ISO-2, which means that this objective was not fully achieved for the dynamic data phase of the demonstration. **Figure 7-1** shows the dynamic IVS position precision graphically.

Table 7-4. TOAR TEMTADS Dynamic IVS Positioning Results

Seed Item	Maximum Error (m)	Average Error (m)
ISO-1	0.23	0.15
ISO-2	0.30	0.20
ISO-3	0.29	0.18
ISO-4	0.18	0.10

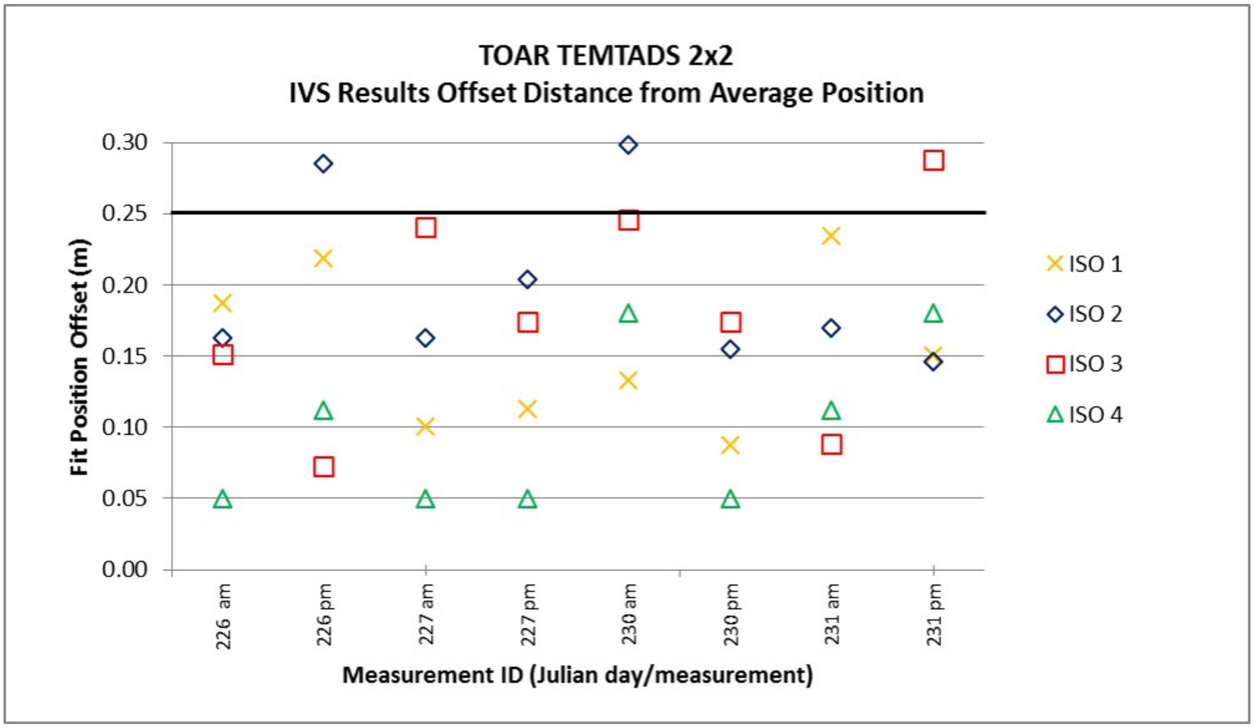

Figure 7-1. TOAR Dynamic IVS Position Precision (Errors Relative to Average Derived Positions)

7.6 INITIAL CUED SURVEY DATA POSITIONING

This objective was to demonstrate positioning accuracy during initial cued data collection with the TEMTADS. The metric was assessed by evaluating the dipole-fit-derived target positions from initial measurements at the IVS. The minimum success criterion was that 100 percent of the fit-derived positions of the IVS targets would be within 25 cm of the ground truth location for the initial IVS measurements. This objective was achieved for the initial IVS cued survey (**Table 7-5**).

Table 7-5. TOAR TEMTADS Initial Cued IVS Survey Positioning Results

Seed Item	Error (m)
ISO-1	0.19
ISO-2	0.16
ISO-3	0.06
ISO-4	0.18

7.7 ONGOING CUED SURVEY DATA POSITIONING

This objective was to demonstrate positioning precision during ongoing cued data collection with the TEMTADS. The metric was assessed by evaluating the dipole-fit-derived target positions from daily measurements at the IVS. The minimum success criterion was that the derived positions of the IVS targets be within 20 cm of the average positions derived from the ongoing daily IVS measurements. As expected, the precision of the measurements was better than the initial accuracy assessment because the initial accuracy assessment factors in ground truth measurement error. The performance criterion for this metric was met (**Table 7-6**). Results for the cued data responses are detailed in **Figure 7-2**.

Table 7-6. TOAR TEMTADS Cued IVS Positioning Results

Seed Item	Maximum Error (m)	Average Error (m)
ISO-1	0.10	0.04
ISO-2	0.12	0.05
ISO-3	0.12	0.05
ISO-4	0.12	0.05

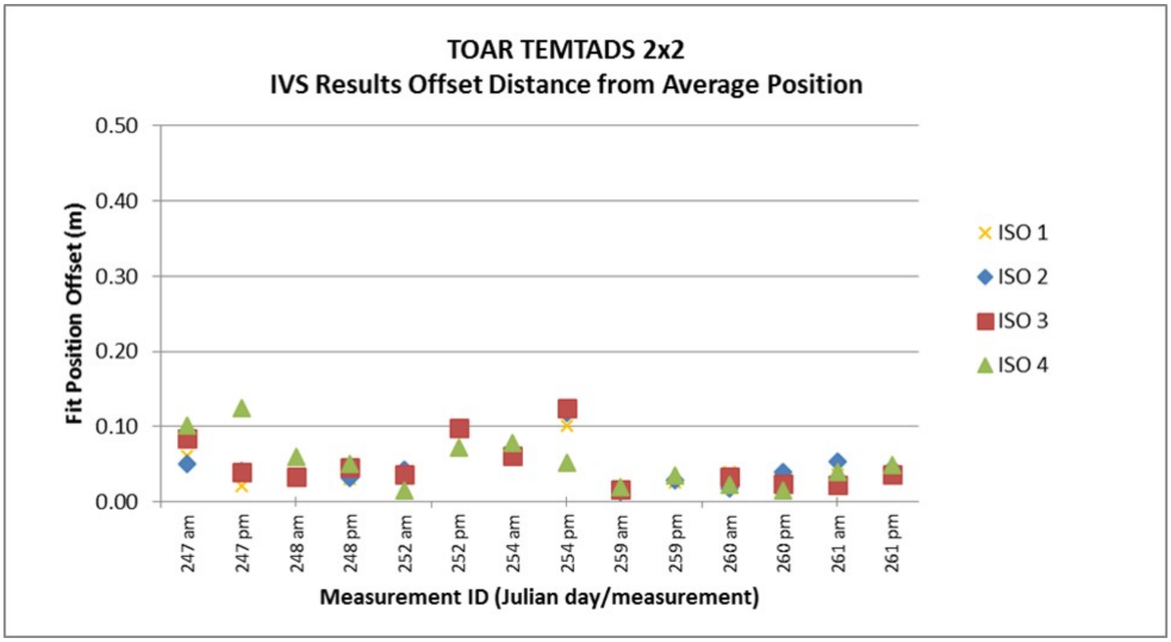

Figure 7-2. TOAR Cued IVS Position Precision (Errors Relative to Average Derived Positions)

7.8 INITIAL CUED MEASUREMENT POLARIZABILITIES

This objective was to demonstrate that the derived polarizabilities of the IVS targets matched the polarizabilities in the library during the initial IVS measurements. The minimum success criterion was met, as the dipole-fit-derived polarizabilities for the IVS targets during initial IVS measurements exhibited a decision metric of ≥0.9 for all IVS ISOs. These results are provided as the first day's data points on **Figure 7-3**.

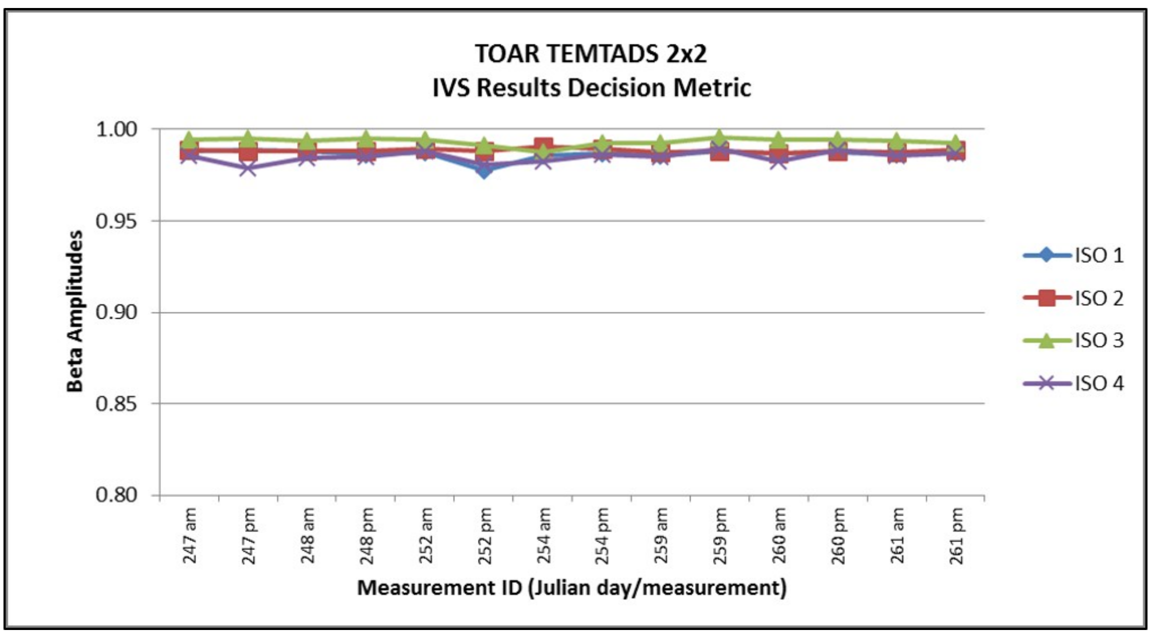

Figure 7-3. TOAR Decision Metric for IVS ISOs

7.9 ONGOING CUED SENSOR POLARIZABILITY PRECISION

This objective was to demonstrate that the derived polarizabilities of the IVS targets from ongoing daily IVS measurements matched the polarizabilities derived from the initial IVS measurements. The minimum success criterion was that the ongoing daily decision metric for the IVS targets was $\geq$0.95. Although the initial IVS signature for each ISO can be used for this test, the matches to the existing library entry were sufficient to pass the MQO, so it was not necessary to use the initial IVS-derived signatures.

7.10 CUED INTERROGATION ANOMALIES

To collect data that support classification, the source of the anomaly must be illuminated along its three principle axes. To ensure this, the sensor array must be positioned directly over the center of the item. The metric for this objective was to demonstrate that the center of the array was within sufficient distance of the anomaly source's location during cued interrogation. Positions of the array center were derived from the RTS and IMU data along with the derived target locations for comparison against each other. The array center positions were compared against the supplied target coordinates as part of the daily QC process during data collection. The minimum and nominal success criterion for this objective was that 100 percent of the final derived targets be positioned within 40 cm of the center of the array. Exceptions include targets that are considered 'cannot analyze' (e.g., saturated response area) and multi-target sources. Thirty-six targets were classified as 'cannot analyze' because the source was too far from the center of the array to support classification. All of the targets not considered 'cannot analyze' had a valid measurement within this metric.

7.11 CORRECT CLASSIFICATION OF TARGETS OF INTEREST

Meeting this objective was a primary key measure of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, targets would be classified with high efficiency. The metric for this objective demonstrates that TOIs are correctly classified as TOIs on the final ranked anomaly list. The ranked anomaly list was submitted to ESTCP for scoring against the emplaced seed items and the intrusive results. The minimum success criterion was correct classification of 100 percent of the seed items and native TOIs as TOIs. Successful achievement of this metric would include seed items and other TOIs categorized as 'dig' or 'cannot analyze' on the final ranked anomaly list. A pseudo receiver operating characteristic (ROC) curve presenting the classification performance is shown in **Figure 7-4.** The ROC curve is derived by moving down the prioritized list and adding 1 to the *y* axis for each recovered TOI and 1 to the *x* axis for each non-TOI recovery. A ROC curve representing perfect classification rises vertically until all TOIs are identified, then horizontally for the remaining non-TOI results. A diagonal ROC curve indicates no classification performance. The results presented in **Figure 7-4** indicate good classification performance. All TOIs were correctly categorized as 'dig'; six TOIs were initially selected as Category -1 (ACDs), and the remaining 26 TOIs were all selected as Category 1 (high likelihood TOI).

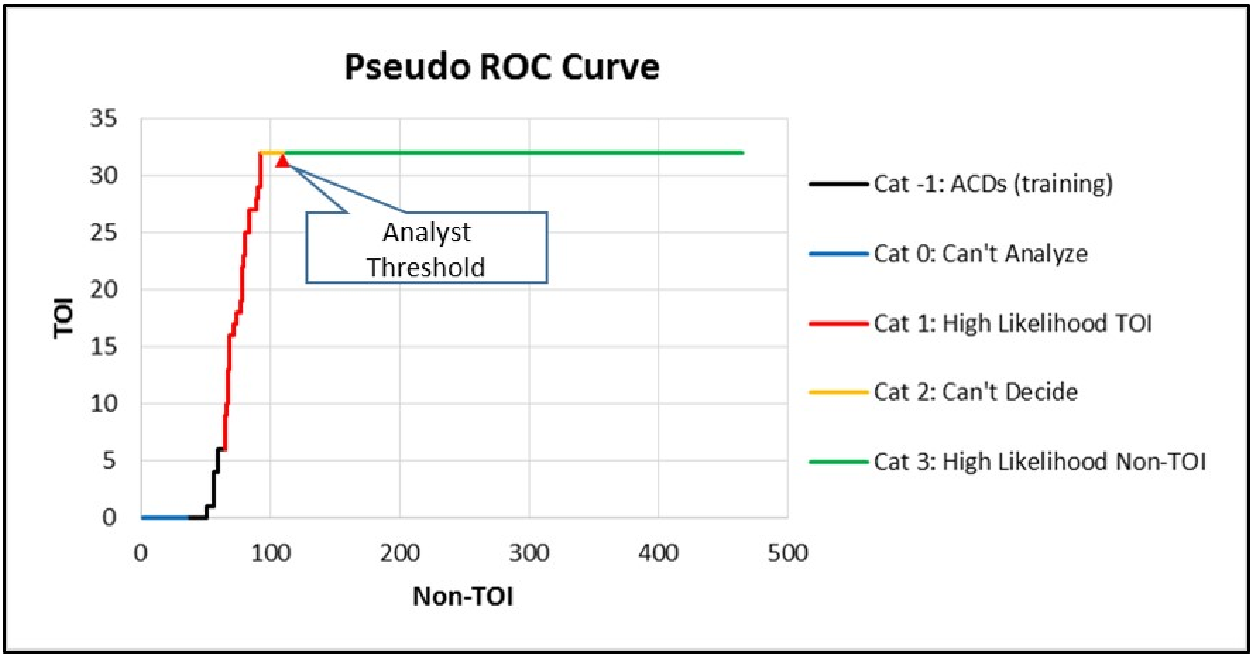

Figure 7-4. TOAR Classification Results for Cued Investigations of 497 Targets

7.12 MODEL RESULTS SUPPORT CLASSIFICATION DECISION

This objective was to demonstrate that data gathered exhibit a measure of the correlation between the model and the observed data, which is used to determine whether the model will support classification. The metric used to validate that the model responses support classification is the percentage of targets that cannot be classified as well as the fit coherence between the model response and observed data. The targets that cannot be classified were identified as having a 'fit coherence' of less than 0.8. (Fit coherence is an output of the UXA dipole fit routine indicating the correlation of the modelled data with the observed responses). The minimum success criterion for the number of targets with responses that support classification was that ≥90 percent of the targets meet the fit coherence requirement. Two targets were categorized as 'can't analyze' because of fit coherence, resulting in 99.6 percent of the targets meeting this metric.

8.0 COST ASSESSMENT

ESTCP projects are required to develop and validate, to the extent possible, the expected operational costs of the technology. The intent of this section is to identify the information that was tracked or the data that were obtained during the demonstrations that will aid in establishing realistic costs for implementing the technology and comparing it to potential alternative technologies.

One of the driving factors for applying classification at munitions response sites is more efficient use of available resources, which can be used to clean up more land more quickly when intrusive investigation of non-munitions targets is reduced. The actual costs of these demonstrations included extensive planning, reporting, and coordination, as well as redundant data collection and processing as these processes had not been standardized at the time of the demonstrations. The costs presented below may not be representative of what would be expected for production application.

8.1 COST MODEL

The tracked costs for NBAFS and TOAR are provided in **Table 8-1 and Table 8-2,** respectively. The costs are shown graphically as **Figure 8-1** for NBAFS and **Figure 8-2** for TOAR. Note that the TEMTADS system was provided by NRL at no cost to CH2M for these demonstrations. The costs per acre (for dynamic data collection) and per anomaly (for cued data collection) do not include the costs that would be associated with procurement of the sensor.

Table 8-1. NBAFS Costs for TEMTADS

Cost Element	Tracked Data	Cost/Quantity
Site Setup		
General site setup	Costs for planning, mobilization, general site setup, shipping of equipment, surface sweep, QC seeding, surveyor services, onsite archaeologists, and demobilization.	$92,000
Dynamic TEMTADS Survey Costs		
Dynamic detection survey and data processing	Dynamic detection survey (6 acres), including: Field labor (three geophysicists/geophysical technicians, one UXO technician), equipment setup, equipment rentals, IVS setup and data collection, data processing, per diem, archaeological oversight	$57,000 ($9500/acre)
Cued TEMTADS Survey Costs		
Reacquisition of cued targets	Reacquisition of anomalies for cued surveys, cued surveys (1500 anomalies), including: Field labor (three geophysicists/geophysical technicians, one UXO technician), equipment setup, equipment rentals, IVS setup and data collection, per diem, archaeological oversight	$110,000 ($73.31/anomaly)
Cued survey data processing	Processing of cued data, including several site visits for task kickoff and quality control purposes	$64,000 ($42.66/anomaly)
Intrusive Investigation		
Intrusive Investigation Costs	Reacquisition of anomalies and all UXO team related costs related to the intrusive investigation and documentation of discoveries per the ESTCP intrusive investigation instructions	$228,000 ($598.16/anomaly)

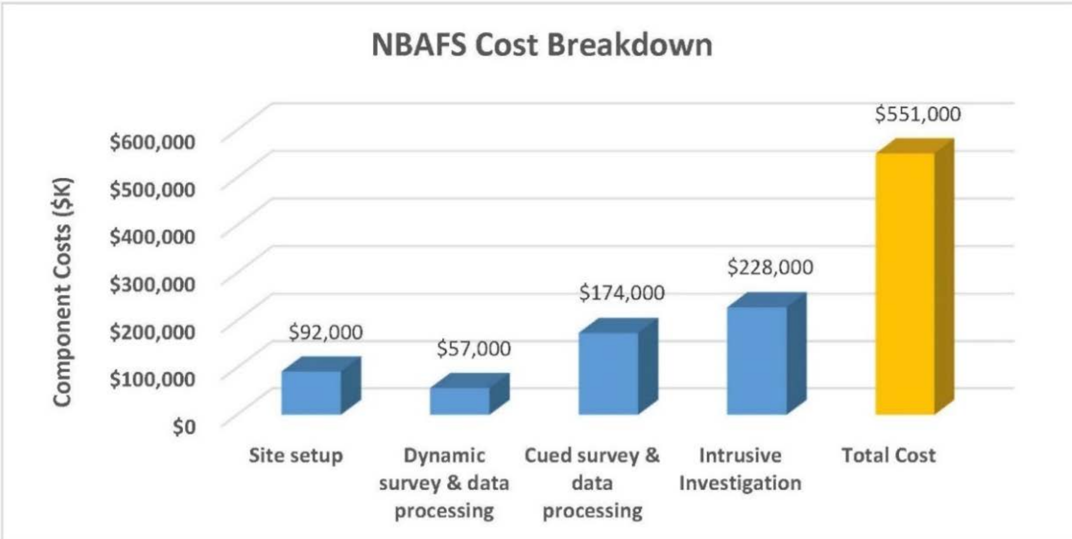

Figure 8-1. NBAFS Cost Breakdown Graph

Table 8-2. TOAR Costs for TEMTADS

Cost Element	Tracked Data	Cost/Quantity
Site Setup		
General site setup activities	Costs for planning, mobilization, general site setup, shipping of equipment, instrument aided visual surface sweep, QC seeding, surveyor services, and demobilization	$63,000
MPPEH and MEC activities	MPPEH management and MEC disposal for the instrument-aided visual surface clearance was de-scoped from CH2M and passed along to the removal action MEC contractor	$5,300
Dynamic TEMTADS Survey Costs		
Dynamic detection survey	Dynamic detection survey (0.89 acre), including field labor (three geophysicists/ geophysical technicians, one UXO technician), equipment setup, equipment rentals, IVS setup and data collection, data processing, and per diem	$77,500 ($87,078/acre) [a]
Dynamic detection data processing	Dynamic detection survey data processing	$8,300
Cued TEMTADS Survey Costs		
Reacquisition of cued targets	Reacquisition of anomalies for cued surveys (497 anomalies), including field labor (three geophysicists/ geophysical technicians, one UXO technician), equipment setup, equipment rentals, IVS setup, data collection, and per diem	$40,000 ($80.48/anomaly)
Cued survey data processing	Processing of cued data, including several site visits for task kickoff and quality control purposes	$6,400 ($12.88/anomaly)
Intrusive Investigation		
Reacquisition of anomalies for intrusive investigation	Reacquisition of anomalies and all UXO team-related costs related to the intrusive investigation and documentation of discoveries per the ESTCP intrusive investigation instructions	$173,200 ($348.49/anomaly)
Management of MPPEH and MEC disposal	Management of material potentially presenting an explosive hazard and MEC disposal for the intrusive investigation was de-scoped from CH2M and passed along to removal action MEC contractor	$11,600

[a] See implementation issues section for explanation of high per-acre cost.
MPPEH = Material Potentially Presenting an Explosive Hazard

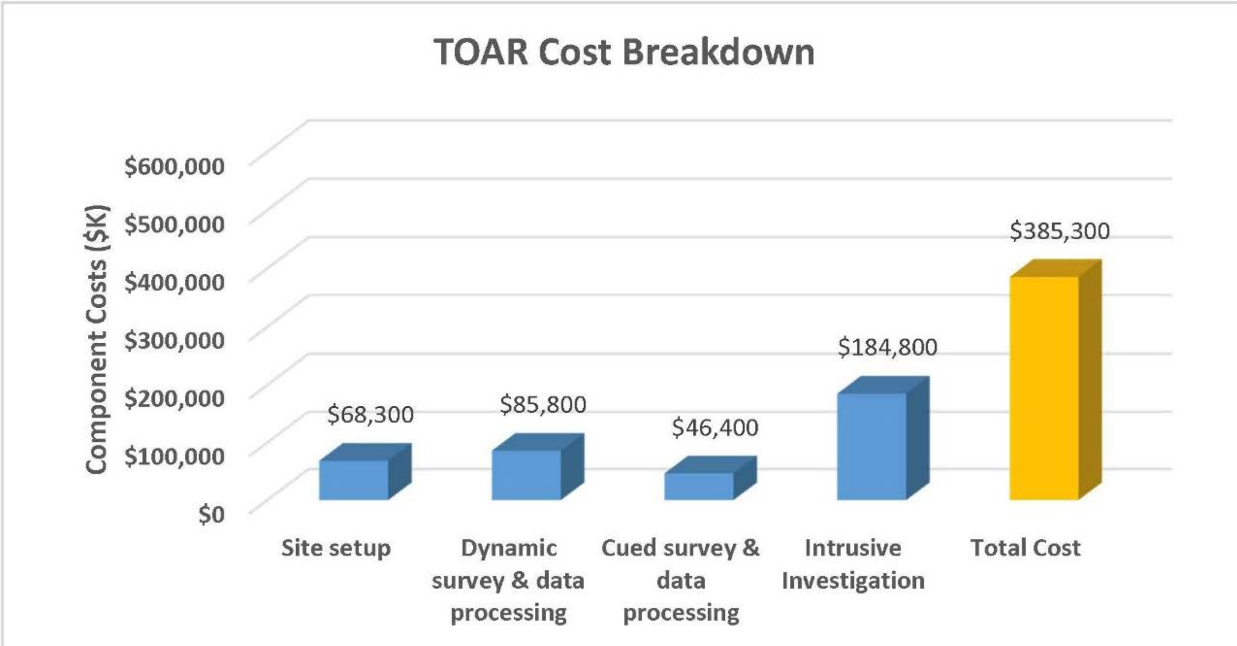

Figure 8-2. TOAR Cost Breakdown Graph

8.2 COST DRIVERS AND BENEFITS

For a typical munitions response project, over 75 percent of the budget is spent on the removal of non-hazardous scrap items. That three quarters of the budget is spent on scrap removal is driven by the fact that DMM/UXO make up 1 percent or less of the metal items on a munitions site. Therefore, a reduction in the number of scrap items that must be treated as potentially hazardous has a large impact on the budget. Classification using advanced technology, such as the TEMTADS, has been proven to greatly reduce the number of scrap items that require intrusive investigation.

Based on the results of the NBAFS demonstration, the TEMTADS was found to be unsuitable for the site conditions encountered and a comparison against potential alternatives is not warranted (because the technology demonstrated is not a viable alternative). The costs associated with the implementation of classification at the NBAFS site are far higher than the costs reported for other demonstration projects. This is a direct result of the high density of metallic items in the subsurface in conjunction with attempting to resolve challenging TOI (20-mm projectiles). Additional factors impacting the cost were the requirement to have on-site archaeological oversight and the high rate of QC involvement in the project. The costs associated with the NBAFS demonstration are not typical of other geophysical classification demonstrations and could likely be considered an outlier. However, the results of the NBAFS demonstration can be used as a point of reference for sites with similar challenging constraints.

Based on the results of the TOAR demonstration, the reduction in the number of clutter items that were treated as potential UXO was 71 percent. It is known from other demonstrations that the data collection and analysis required to implement classification requires more resources than a conventional detection survey, however, these costs were enhanced at TOAR. At TOAR, data collection production rates were hindered because of a variety of challenging conditions including (but not limited to) dense woods, long travel times to and from the site, and TEMTADS software and hardware issues[1]. These factors served to increase the costs associated with data collection and data processing. However, even taking into consideration these added up-front costs the savings in the intrusive phase are more than repaid. Based on the results at the TOAR demonstration, a similar reduction (71 percent) in the number of clutter items treated as potential UXO should be possible at most sites with similar or less challenging conditions.

1 These issues are discussed in more detail in Section 9, Implementation Issues.

9.0 IMPLEMENTATION ISSUES

As discussed in Section 8, one of the most important implementation issues related to the TEMTADS technology is the need to demonstrate that the technology can significantly reduce the cost of remediation. Even with the reduction in the costs associated with intrusive investigation of non-hazardous scrap, the cost for deploying the TEMTADS will, at least in the short term, remain significantly higher than the cost for commercially available conventional technology such as the Geonics EM61-MK2.

Additionally, because of the experimental nature of the TEMTADS at the time of the demonstration, the sensor is not considered standard commercial off-the-shelf. Because of the specialized nature and lack of availability of the technology, time was lost because of software and hardware issues that required NRL support for solutions during both demonstrations. The TEMTADS can be deployed in the field using personnel with the same technical skills as those who routinely conduct UXO-related geophysical mapping surveys. However, data processing tends to be more demanding than for conventional surveys.

9.1 IMPLEMENTATION ISSUES SPECIFIC TO NBAFS

The underlying premise of geophysical classification is that remediation costs can be reduced by classifying an anomaly source as TOI or non-TOI, thus limiting intrusive investigation to those anomalies that are potentially TOI. This premise assumes that the percentage of targets that are potentially TOI is sufficiently small and the cost savings associated with reducing the number of required excavations is greater than the cost of implementation of classification. Using generic assumptions of $50 per anomaly for classification (more typical than the costs experienced on the NBAFS project) and $200 per excavation (also more typical) as a starting point, a minimum dig reduction of 25 percent is required to offset the cost of classification (obviously any benefit realized would require more than a 25 percent reduction and would be directly proportional to the percent reduction). The intrusive results at NBAFS indicate that, even with perfect classification, the maximum dig reduction at the site could only be 30 percent. Clearly classification does not offer the potential for cost savings at this site, especially if 20-mm projectiles are included in the TOI list. A 20-mm projectile is one of the smallest items that can be reliably detected using digital geophysical mapping methods and therefore has a low SNR. At NBAFS there were many 20-mm targets throughout the site. This made the classification problem especially challenging for two reasons

- The high percentage of multi-target scenarios where signatures overlapped
- The size of scrap fragments at NBAFS were often similar in size to 20-mm projectiles

In addition to the percent of TOI, the number of sources encountered for each anomaly significantly impacted the usability of the results. Approximately 33 percent of the anomalies investigated resulted in more than three sources – under these circumstances the inversion results do not appear to accurately represent the ground truth. Additionally, there currently is no way to use the inversion results to reliably determine the number of sources, so there is no way to prove that the inversion results are valid when the anomaly density (and, by implication, source density) is as high as demonstrated at NBAFS.

9.2 IMPLEMENTATION ISSUES SPECIFIC TO TOAR

While the RTS can be used for positioning in open areas or narrow corridors, the TEMTADS unit cannot be carried in such a way that it is always moving perpendicular to the RTS base station, and thus avoid being shielded from the base by the operators. In order to facilitate positioning in a heavily wooded area using RTS, the RTS prism located above the TEMTADS unit had to be raised above the heads of the operators. This allowed free movement by the operators and increased the data production rate; however, the added height of the prism more than likely caused dynamic IVS measurement MQO failures because of the oscillation of the prism while walking. Additionally, dynamic data with a lower prism height were not collected, so it is not possible to rule out that just walking in litter mode with the RTS was not the issue. Prior experience using the RTS with the TEMTADS in wheeled mode had no positioning MQO failures.

Data collection production rates were hindered for the following reasons:

- Approximately 1.5 hours of travel time was needed after reaching the site each day to access the collection grids.
- Daily reassembly and breakdown were required, as there was no secure storage facility. A temporary carport was installed for a partial breakdown area; however, cables needed to be secured nightly because of animal activity.
- Setting up the RTS base stations in multiple locations took more time than a standard RTK GPS set up. There was also a steep learning curve for speedy assembly of the RTS; this often delayed the start of production.

Because of the experimental nature of the TEMTADS, several days of production were lost because of software issues and a hard drive failure, which resulted in multiple trips to NRL for solutions.

10.0 CONCLUSIONS

CH2M performed ESTCP MR Live Site Demonstrations at NBAFS, NH, in the summer of 2013, and at MRS R-04A West site at TOAR FUDS, Pennsylvania, in the summer of 2015. The demonstrations involved the use of the TEMTADS EMI sensor for classification at sites designed to challenge the technology by:

- Investigating the classification methodology at a site that was suspected to contain both a high density of subsurface metal as well as a large variety of munitions down to 20-mm projectiles (NBAFS)
- Investigating the efficacy of the sensor at a densely wooded site with challenging micro-terrain features (e.g., impact craters, rocks, boulders, gullies) for detection of munitions down to the size of 37-mm projectiles (TOAR)

The NRL TEMTADS was demonstrated in both dynamic and cued modes. It was deployed on its standard wheels at NBAFS and in a two-person litter configuration at TOAR. At NBAFS positioning was achieved with a RTK GPS and at TOAR with a Trimble RTS.

At NBAFS, approximately 6.1 acres were mapped with the TEMTADS. Evaluation of the dynamic data resulted in the selection of 18,373 targets. As the density of geophysical anomalies identified was an order of magnitude greater than anticipated, a subset area of the site was chosen for cued investigation and 1,500 anomalies were identified for cued interrogation. The demonstration was halted several weeks into the dig program as it was determined that use of AGC technology at this site would not result in cost savings and would not be effective with respect to classification. Intrusive investigations yielded TOI at 70 percent of each dig location. Additionally, approximately 33 percent of the anomalies investigated resulted in the recovery of three or more sources and under these circumstances the inversion results do not appear to accurately represent the ground truth. These results indicated that submission of a final prioritized list would add no value to the demonstration. Additionally, given the failure of the derived signatures to accurately predict the anomaly sources when more than 3 sources were recovered and the high percentage of multi-target scenarios, an analysis of the system's performance against the few seeds on the cued interrogation list was not undertaken as added no value to the demonstration.

At TOAR, approximately 0.71 acre was dynamically surveyed with the TEMTADS system. Production was significantly hindered by the remote location and site conditions, and only one of the four grids initially selected for investigation achieved 100 percent coverage (not including gaps because of physical obstructions). Based upon this effort, production rates under less challenging conditions are estimated to be much higher. A total of 429 anomalies were identified by the TEMTADS dynamic data analysis. These anomaly locations and an additional 68 targets selected by the MPV survey were interrogated (cued data collection) and classified with the TEMTADS system. The targets were subsequently classified as being a potential TOI (dig) or high-likelihood non-TOI (do not dig). All known TOI (seeds and native) were successfully detected and classified. From the perspective of demonstrating the potential for cost savings and risk reduction, the TOAR study was successful. The data analyst was able to correctly identify all the munitions on the anomaly list with an approximately 22 percent rate of false positives. This resulted in a 71 percent reduction in the number of intrusive investigations necessary.

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